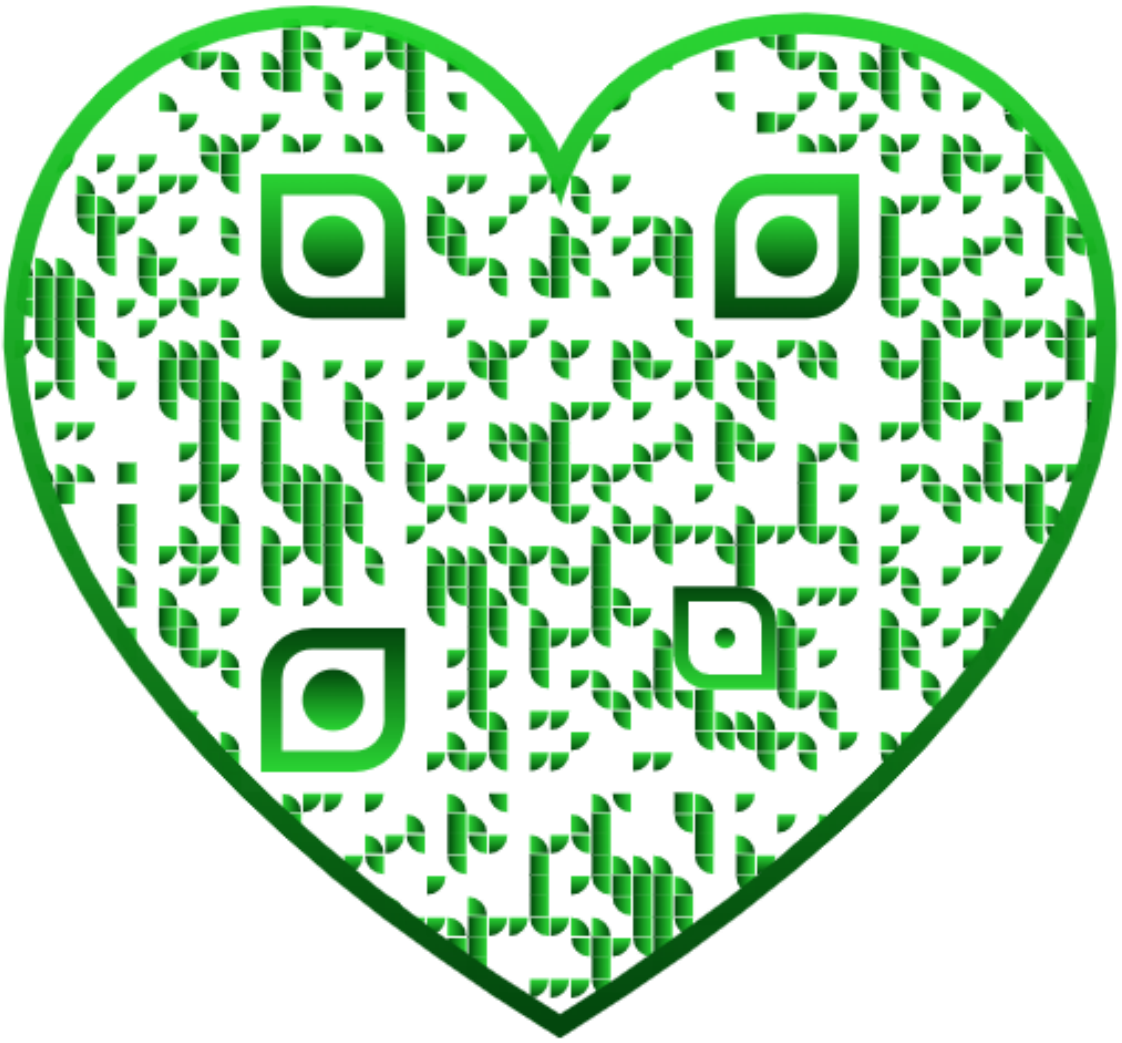
JOHN MASON

COMMERCIAL HYDROPONICS

THIRD EDITION



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PREFACE

Hydroponics has a dedicated following worldwide; of both amateur and commercial growers. This book, though titled "Commercial", is still very much a relevant reference for the amateur.

Over the 20 years since we published the first edition, Hydroponics has become a significant and stable facet of horticulture in many countries. It has been recognised for its environmental as well as commercial benefits; and an ever increasing variety of techniques and applications have emerged. Organic hydroponics is even possible today.

Hydroponics offers more than anything else, possibilities for plant culture that did not exist before. In a hydroponic system, many of the manual tasks, and costs involved in soil culture can be eliminated, but there is a trade off. The set up costs are normally higher. Hydroponics can make better use of limited water resources, and can reduce or eliminate the need for chemical pest control in a commercial situation. Hydroponic produce can in fact be less tainted by chemical residues than produce from a traditional farm.

I was asked to write the first edition of this book in 1988 by David Rosenberg, founder of Kangaroo Press. Despite being a relatively new branch of Horticulture, there were already plenty of hydroponic books on the market around the world. There was one thing that was still scarce in most books: information about different types of plants and how to grow them in hydroponics. A significant part of the original book was devoted to this plant information. With assistance from my staff at Australian Correspondence Schools we surveyed leading hydroponic experts and growers, interviewing them over the phone. We asked them about how to grow 87 different plants in hydroponics and then documented the results.

Over the 20 years that the first edition was in print, it has been printed nine times, making it an exceptionally successful book, particularly being of such a specialist nature.

I wish to thank all of those who have purchased and used the first editions, and I trust the second edition will be even more useful to you.

The second edition saw us talking again with experts, and gathering information from literature to expand and update every part of the book, but in particular, plant cultural information.

This third edition has been produced as an e-book; in response to the changing nature of publishing worldwide. It is an all new layout, with some additional changes.

With this new electronic format, we have been given tools to make further editions and changes whenever we want. It is our intention to review the book and add further information periodically as we move forward into the future.

This book has come together with a great deal of support and assistance from a large number of people over many years, as you will see in the acknowledgements. I wish to sincerely thank everyone who has assisted me.

I hope you find the reading both enjoyable and useful.

John Mason FIOH, FAIH, FPLA

Note:

The information in this book is derived from a broad cross section of resources (research, reference materials and personal experience) from the authors and editorial assistants in the academic department of ACS Distance Education. It is, to the best of our knowledge, composed as an accurate representation of what is accepted and appropriate information about the subject, at the time of publication.

The authors fully recognise that knowledge is continually changing, and awareness in all areas of study is constantly evolving. As such, we encourage the reader to recognise that nothing they read should ever be considered to be set in stone. They should always strive to broaden their perspective and deepen their understanding of a subject, and before acting upon any information or advice, should always seek to confirm the currency of that information, and the appropriateness to the situation in which they find themselves.

As such, the publisher and author do not accept any liability for actions taken by the reader based upon their reading of this book.

CHAPTER 1 : INTRODUCTION

Hydroponics is the technique of growing plants without soil. The roots grow either in air, which is kept very humid; in water, which is well aerated; or in some solid, non-soil medium, which is kept moist. The water around the roots contains a carefully balanced mixture of nutrients which provides food for the plant.

There are three main ways of growing plants hydroponically:

Aggregate culture

Small particles of chemically inert substances provide a suitable environment for the plant roots to grow through.

Rockwool culture

A fibrous sponge-like material made from molten rock provides an environment for the roots to grow through.

Water culture

Water, perhaps mixed with air (with no solid material), provides the environment in which the roots grow.

The aggregate, rockwool or water which is used to provide the root environment, supplies the physical needs of the roots.

The roots (and in fact the whole plant) also have chemical needs which must be catered to. The chemical needs are supplied by adding a carefully calculated solution of nutrients to the root zone, and maintaining the balance of chemicals in that solution at appropriate levels.

Hydroponics has also been called 'soilless culture', 'nutriculture' and 'chemiculture'.

rockwool culture

HISTORY

The word hydroponics comes from two Greek words: *hydro* meaning water and *ponos* meaning labour. This word was first used by Dr W.F. Gericke, a Californian professor who in 1929 began to develop what had previously been a laboratory technique into a commercial means of growing plants. Throughout the 19th Century a number of scientists undertook significant research into the nature of plant nutrition. Classical experiments conducted by German plant scientists, Sachs in 1860 and Knop between 1861 and 1865, led to our first understanding of what were essential plant nutrients. Chemical formulae developed by Sachs and Knop, and several other researchers who followed them, provided Dr Gericke with the knowledge to make an effective nutrient solution, thus overcoming the major restriction to the development of hydroponic culture.

Plants had been grown hydroponically before Dr Gericke, but only as laboratory experiments or (in the case of some earlier civilisations) without a proper understanding of the methods being used. Dr Gericke is credited with having recognised the commercial potential of what he had seen as a laboratory technique, and having conducted trials which inspired the development of a commercial industry in the following decades.

Scientists in North America, Europe and Japan, inspired by Dr Gericke's experiences, worked throughout the 1930s and 40s to refine our knowledge of hydroponic growing. The United States army used hydroponic culture to grow fresh food for troops stationed on infertile Pacific Islands during World War II. By the 1950s there were viable commercial hydroponic farms operating in America, Britain, Europe, Africa and Asia.

Interest in hydroponics developed in Australia throughout the 1960s, and in the 1970s many vegetable growers, inspired by tales of increased production, attempted to convert their operations to hydroponics. Unfortunately many of these people failed to do their 'homework', and embarked upon schemes without having a real understanding of the differences between soil and hydroponic culture. The result was many failures, and the development of an attitude in Australia that hydroponics doesn't really work.

In 1981 CSR Ltd established an Australian plant to produce horticultural grade rockwool for hydroponic production. CSR did their homework, promoted their product well and supported it with excellent technical information. As a result, Growool (as it is known) became widely accepted, and today is used extensively in the Australian cut flower industry.

At the beginning of the 21st century commercial crops of vegetables, berry fruit, and cut flowers are grown extensively by hydroponic culture in many countries. The most popular technique worldwide is rockwool culture, though NFT (Nutrient Film Technique), perlite and gravel bed culture are all very significant techniques in use in commercial hydroponics.

HOW PLANTS GROW

To understand and practice hydroponics successfully requires the grower to have an understanding of how plants grow.

Almost all plants grown in hydroponics are flowering plants. These plants have four main parts:

Roots – the parts which grow below the soil

Stems – the framework

Leaves – required for respiration, transpiration and photosynthesis

Reproductive parts – flowers and fruits.

Roots

Soil provides the plant with the following:

- Nutrients
- Water
- Air
- Support

Roots absorb nutrients, water and gasses, transmitting these 'chemicals' to feed other parts of the plant. Roots hold the plant in position and stop it from falling over or blowing away.

When we grow a plant in hydroponics, we must make sure that nutrients, water and air are still supplied and that the plant is supported, as would occur if it was growing in soil.

Nutrient supply in soil is a more complex matter than in hydroponics. Plant nutrients can be supplied, broadly speaking, in three different forms:

Water soluble simple chemical compounds

Nutrients in these compounds are readily available to plants (i.e. the plant can absorb them quickly and easily).

Less soluble simple chemical compounds

The nutrients in these compounds can be used by plants without needing to undergo any chemical change, but because they don't dissolve so easily in water they aren't as readily usable as the more soluble compounds. The diminished solubility may be because of the nature of the compound (e.g. superphosphate) or may be due to something else (e.g. slow-release fertilisers such as Osmocote, which is made by incorporating the simple chemicals inside a semi-permeable bubble – thus nutrients move slowly out of the bubble).

This second group of nutrients, when placed in soil, will last longer than the first group of water soluble nutrients.

Complex chemical compounds

These require chemical changes to occur before the nutrients can be absorbed by plants. They include organic manures and fertilisers which need to be broken down by the soil microorganisms into a form which they can use. They also include other complex fertilisers which need to be affected by natural acids in the soil, or heat from the sun, to become simple compounds which the plant roots can use.

Complex chemicals release their nutrients gradually over a long period of time, depending on the range of chemical changes needed to take place before the plant can use them.

Plants grown in a soil derive their nutrients from all three types of compounds. The availability of these compounds varies not only according to the group they come from but also with factors such as heat, water, soil acids and microorganisms present. Consequently it is impossible to control the availability of nutrients in soil.

This is one intrinsic advantage of hydroponics over soil growing. In hydroponics you can choose to use only simple, soluble compounds, and so you can determine the exact amount of each essential nutrient available to a plant at any point in time.

Stems

The main stem and its branches are the framework that support the leaves, flowers and fruits. The leaves, and also green stems, manufacture food by the process known as photosynthesis, and this is transported to the flowers, fruits and roots. The vascular system within the stem consists of canals, or vessels, which transfer nutrients and water upwards and downwards through the plant. This is equivalent to the blood system in animals.

Leaves

The primary function of leaves is photosynthesis, a process in which light energy is caught from the sun and stored via a chemical reaction in the form of carbohydrates such as sugars. The energy can then be retrieved and used at a later date if required in a process known as respiration. Leaves are also the principle plant part involved in the process known as transpiration whereby water evaporating, mainly through leaf pores (or stomata), sometimes through the leaf surface (or cuticle) as well, passes out of the leaf into a drier external environment. This evaporating water helps regulate the temperature of the plant. This process may also operate in the reverse direction whereby water vapour from a humid external environment will pass into the drier leaf.

The process of water evaporating from the leaves is very important in that it creates a water gradient or potential between the upper and lower parts of the plant. As the water evaporates from the plant cells in the leaves then more water is drawn from neighbouring cells to replace the lost water. Water is then drawn into those neighbouring cells from their neighbours and from conducting vessels in the stems. This process continues, eventually drawing water into the roots from the ground until the water gradient has been sufficiently reduced. As the water moves throughout the plant it carries nutrients, hormones, enzymes, etc. In effect this passage of water through the plant has a similar effect to a water pump, in this case causing water to be drawn from the ground, through the plant, and eventually out into the atmosphere.

Reproductive parts

Almost all plants grown in hydroponics are flowering plants. These reproduce by pollen (i.e. male parts) fertilising an egg (i.e. female part found in the ovary of a flower). The ovary then grows to produce a fruit and the fertilised egg(s) will grow to produce seed.

There can sometimes be difficulty in obtaining a good crop because insufficient pollen reaches the female parts, resulting in insufficient fruit forming. (This is discussed in chapter 11.)

blueberries

CLASSIFICATION OF HYDROPONIC SYSTEMS

There are two main groups of systems:

Water culture

Nutrients are dissolved in water which is brought in contact with the roots. Water is either aerated or roots are allowed to contact air as well as nutrient solution.

Trellis, wire mesh or some other support is provided above the nutrient solution

Examples

Nutrient tank

Standard jar

Nutrient film (NFT)

Mist systems

Aggregate culture

Nutrients are dissolved in water which is moved into the root area. The roots are grown in a solid, inert (nutrient-free) material, which is able to hold sufficient moisture but drain off the excess, allowing adequate aeration. The solid material which the roots grow in contributes towards (if not fully supplying) anchorage.

Examples

Beds and tier systems.

The Variables of a System

The types of hydroponic system that can be used vary for a range of reasons. The most common variables are:

1. *Solution dispensation* -closed or open (i.e. the solution is recycled or drained through and lost) -drip, slop, capillary feed, wicks, misting, dry fertilising etc.
2. *Automatic or manual operation*
3. *Type of medium* -gravel, vermiculite, perlite, sand, scoria, peat, expanded clay, a mixture etc.
4. *Construction materials* -concrete, fibreglass, plastic, glass, wood, masonry, metal, PVC, ceramic, polystyrene, etc.
5. *Rate and frequency of irrigation and feeding*
6. *Air injection* (in water culture, where air is pumped into nutrient solution to raise the oxygen level)
7. *Plant support* -trellis etc.
8. *Environmental controls* -temperature, ventilation etc.

OVERVIEW OF THE INDUSTRY

Commercial hydroponics is a successful and rapidly expanding industry. Industry growth has been particularly dramatic in the last decade. In the early 1990s there were around 5000 hectares of commercial hydroponic production worldwide. By 2001 there were an estimated 20,000 to 25,000 hectares under hydroponic production, and this strong growth in global commercial production is expected to continue over the next few years.[1]

Commercial production is centred in affluent countries with discerning customers – The Netherlands, Spain, Canada, UK, US, Australia, NZ, Italy and Japan. The major producer is Holland, with around 10,000 hectares under production, followed by Spain, Canada and France. Australia is ranked as the tenth major producer in the world, and the leading producer of fancy lettuce. Expansion in the US has been slower; in 1998 the US ranked as the sixteenth largest producer, although a recent surge in large commercial installations is likely to boost their production. [2]

Although, as this book shows, many crops can be grown successfully in hydroponics, worldwide commercial production is limited to a few crops: tomatoes, cucumbers, lettuce, capsicums and cut flowers (including roses, gerberas, carnations, chrysanthemums and lisianthus).

In most countries the majority of hydroponic crops are grown in greenhouses, the exception being Australia where more than 50% of hydroponic production takes place outdoors (due to the high proportion of lettuce grown). In Holland nearly all greenhouses have converted to rockwool and NFT culture as a consequence of soil depletion, salinisation, a build-up of soil-borne diseases, high water tables and good economic returns.

The most popular systems worldwide are NFT and rockwool culture, although other systems are used for commercial production. In all countries systems are moving towards recirculation, due to the potential environmental problems caused by run-to-waste systems.

Other sustainable practices such as 'organic hydroponics' (chapter 4) and Integrated Pest Management (IPM) are seen to be important strategies for future production. Currently more than 70% of Dutch hydroponic production relies on IPM (for tomatoes and capsicums it is more than 90%).[3]

Gazania

WHY PRACTICE HYDROPONICS?

Hydroponics has been practiced by market gardeners and other growers since the 1940s. The advantages of hydroponics are many; however, the disadvantages should not be overlooked when you are deciding whether or not to set up a hydroponics system.

Advantages

1. You can grow anywhere

Crops can be grown where no suitable soil exists or where the soil is contaminated with disease.

2. Culture is intensive

A lot can be grown in a small space, over a short period of time. It is also possible to grow in multi-levels. Where transportation costs to the market are significant (e.g. in the centre of large cities), hydroponic farms may be viable irrespective of land values. For example, in Japan hydroponic vegetables are grown in supermarkets in the centre of large cities. The savings on transport costs and the benefits of having fresh produce offsets the increased cost of space in these cities.

3. Heavy work is reduced

Labour for tilling the soil, cultivation, fumigation, watering and other traditional practices can be reduced and sometimes eliminated.

4. Water is conserved

A well-designed, properly run hydroponic system uses less water than gardening. This is an important advantage in areas with poor quality or limited water supplies. In particular, hydroponics is seen to have potential benefits in controlling water pollution in developing countries.

5. Pest and disease problems are reduced

The need to fumigate is reduced. Soil-borne plant diseases are more easily eradicated in many nutriculture systems. This is particularly true in 'closed systems' which can be totally flooded with an eradicant. The chance of soil-borne human disease is also reduced. Though rare in developed countries, it is possible for diseases to be transmitted from animal manures or soil microorganisms onto food plants grown in soil, leading to illness.

6. Weed problems are almost eliminated

Weeds are a major problem in most soil-based systems. Weeds are almost non-existent in hydroponic setups.

7. Yields can be maximised

Maximum yields are possible, making the system economically feasible in high density and expensive land areas.

8. Nutrients are conserved

This can lead to a reduction in pollution of land and streams because valuable chemicals needn't be lost.

9. The environment is more easily controlled

For example, in greenhouse operations the light, temperature, humidity and composition of the atmosphere can be manipulated,

[1] Hassall and Associates Pty Ltd, *Hydroponics as an Agricultural Production System*, RIRDC Publication No 01/141, November 2001.
[2] Steven Carruthers, A Global Perspective, *Practical Hydroponics*, Issue 42, 1998.
[3] Steven Carruthers, Hydroponics As An Agricultural Production System, *Practical Hydroponics*, Issue 63, 2002.

banana

while in the root zone the timing and frequency of nutrient feeding and irrigation can be readily controlled.

10. Root zone chemistry is easier to control

Salt toxicities can be leached out; pH can be adjusted; EC (electroconductivity) can be adjusted. Also salts will not bind chemically to the majority of media used in hydroponics so problems of salt build-up that may occur in soils, particularly when highly soluble nutrients are used, are uncommon in hydroponics.

11. New plants are easier to establish

Transplant shock is reduced.

12. Crop rotation/fallowing is not necessary

All areas can be used at all times – you don't need to leave a paddock for a year to fallow every so often.

The amateur horticulturist can use hydroponic systems at home, even in high rise buildings. A nutriculture system can be clean, lightweight, and mechanised.

Disadvantages

1. Initial cost is high

The original construction cost per hectare is great. This may limit you to growing crops which either have a fast turnover or give a high return.

2. Skill and knowledge are needed to operate properly

Trained plantsmen must direct the growing operation. Knowledge of how plants grow and the principles of nutrition are important.

3. Diseases and pests can spread quickly through a system

Introduced diseases and nematodes may be quickly spread to all beds using the same nutrient tank in a closed system.

4. Beneficial soil life is normally absent

5. Plants react fast to both good and bad conditions

The plants in hydroponics react more quickly to changes in growing conditions. This means that the hydroponic gardener needs to watch his plants more closely for changes.

6. Available plant varieties are not always ideal

Most available plant varieties have been developed for growth in soil and in the open. Development of varieties which are specifically adapted to more controlled conditions may be slow to occur.

CHAPTER 2 : SITE CONSIDERATIONS

What you grow successfully in a hydroponic installation is largely dependent on where you are located. The local climate, availability and quality of water and local demand for what is grown are all key considerations.

hydroponics house

CLIMATE

Climate affects what can be grown, and at what times of the year it can be grown. Even with the help of greenhouses or other environmental controls, the outside environment still has a great bearing upon the economic viability of using hydroponic systems.

It is not simply a matter of the quality of the environment, quantity is also critical. For example, to grow cucumbers it is not enough to just get warm weather, the *number* of days of warm weather is also critical.

Some of the more important factors to consider are:

Temperature

Temperature affects the development of flowers or fruit in many different types of plants. Very often the plant not only needs the temperature to be at a certain level, but it needs the right sequence of day temperatures. For example, many chrysanthemums need a sequence where day temperatures are warm during the early stages of flower development but gradually become cooler as the flower buds develop and approach maturity.

Frost-sensitive period

Frost can kill or severely damage a crop. Bad frosts will to some extent even penetrate the walls of a greenhouse, burning plants inside. Even plants which are generally tolerant of frosts can be badly damaged if the frost occurs at the wrong time of year:

- Virtually all fruit or flower buds are susceptible to frost. If frosts are likely to occur at a time close to when flower buds open, fruit development may be stopped even if the rest of the plant is unaffected.
- Some young seedlings are killed by frost.
- Tender, lush new growth is more susceptible to frost.

You need to know when frosts are likely to occur on a particular site, and select crops for that site which do not have a high risk of frost damage.

Day length

Day length, along with temperature, is the most important factor in causing flower buds to form and fruit to develop. For some plants, the appropriate sequence of day length must take place for you to achieve a good crop. For other plants a minimum or maximum day length must occur before flower buds will form. For example, African violets require at least 16 hours of daylight – or artificial light – for flowering to occur.

Brightness

For some plants, the intensity of light is just as critical as the length of light period. Many vegetables and herbs do not produce the same quality or quantity of yield if light intensities are too low. Other plants must have lower light intensities, preferring shaded conditions.

A slope which catches the midday sun (i.e. north facing in the southern hemisphere) will have higher light intensities than one facing away from the afternoon sun. A site covered by tall trees or beside tall buildings will have lower light intensities than one facing away from the afternoon sun. A site in a valley may have lower light intensities than one on a ridge or a flat plain.

Rainfall

In low to medium rainfall areas, there is generally less need for hydroponic installations to be covered than in high rainfall areas, where the rainfall can dilute nutrient solutions or leach nutrients out of the system.

Humidity

Humid environments are suitable for some crops and unsuited to others. High humidity generally increases the likelihood of fungal diseases. Pollen may become more sticky and move around less easily in very humid situations. This can lead to a decrease in pollination of flowers which in turn may decrease the number of fruit forming.

Evaporation

Consider how fast water is lost through evaporation. This may influence your choice of hydroponic system. Some systems minimise loss through evaporation more than others.

Aspect

The best site will be relatively flat but with a slight slope to allow water to drain away. The site should not be prone to flooding.

A north-facing slope (in the southern hemisphere) will catch winter sun and be less prone to cold southerly winds or frosts. Sites in valleys are more prone to frosts, and will not become as warm in summer.

Wind

Wind can damage plants and greenhouses. In wind prone areas, it may be advisable to plant a windbreak to provide protection.

Some wind is needed for proper cross-pollination with certain crops. Air movement can also be beneficial by stopping disease spores from settling in one place and infecting a plant.

The crops, therefore, that you choose to grow should match the climatic patterns of the site.

WATER REQUIREMENTS

Water quality and quantity have a very important effect upon the viability of any hydroponic installation. You may get water from town water supplies, a river or other watercourse, rainfall, dams, bores or even distilled sea water. In today's increasingly polluted world, no water supply can be guaranteed to remain suitable for any great length of time. Watercourses in Australia are increasingly being affected by rising levels of salts. Acid rain is contaminating water supplies in Europe and America. You may need to face the prospect of treating water to remove impurities at some stage in the future if the quality of your supply is not very clean.

Water with sodium levels below 500 ppm can be used for hydroponics, though much lower levels are preferred. The types of salts making up the ppm value will affect the salinity level that plants will tolerate. Water can contain a large range of minerals - some are useful and will be taken up by plants, in which case the nutrient formulation for the crop needs to be adjusted for the presence of these to prevent accumulation and nutrient imbalances.

Useful minerals often found in many water supplies are calcium, magnesium, sulphur and various trace elements. The most common problematic salt found in natural water supplies is sodium which is often found in high levels in wells, dams and even municipal water sources in countries such as Australia and Africa. Sodium is not taken up by plants to any great degree and will accumulate in nutrient solutions and growing media, creating salt problems. Other common water quality problems are the presence of iron or trace elements such as boron, copper, manganese and zinc, which are required by plants, but such small quantities they can easily accumulate to toxic levels when present in the water supply.

Crops also vary with their tolerance to minerals in the water supply. Lettuce crops should not be grown in NFT with sodium levels in the water supply much above 40ppm. Salt-tolerant crops such as tomatoes in a media system can tolerate water supplies with as much as 300ppm sodium provided this is monitored in the leachate.

Some water supplies contain very small quantities of other chemicals which will severely affect the crop potential. It is important that you know the quality of your water very well, and that you test it on a regular basis. Water quality can vary considerably over time, so even if your water tests out as being suitable when you first start, it may subsequently change, sometimes very quickly.

Quantity

Water requirements will vary greatly according to:

- *Size* - larger plants generally need more water.
- *Wind conditions* – windy sites need more water.
- *Humidity* – high humidity reduces water requirements.
- *Rainfall* – if the system is in the open, natural rainfall may add to the water supply (though it may affect nutrient solution concentration).
- *Temperature* – hot places lose more water through evaporation.
- *Type of hydroponic system* – recirculating systems need less water than run-to-waste systems. Highly absorbent media need less water than poorly absorbent ones. There is less water loss when the

root zone is surrounded by a water impermeable layer (e.g. NFT inside a fully enclosed pipe).

Most systems will use between 0.25 and 1.25 litres of water per day per square metre of growing surface, with the average unit normally using 0.5 to 0.6 litres per square metre per day.

Quality

Hard water is that which contains magnesium and calcium salts. In the presence of soaps, hard water forms a sludge. Hard water can be used for hydroponics provided it does not contain too much calcium carbonate.

Copper, zinc, and several heavy metals such as lead or mercury can be found as contaminants in some waters. These can damage or kill plants. Excessive levels of these metals can be removed by slow filtration through a bed of calcareous material, e.g. limestone chips or dolomite.

Free chlorine in large quantities (as found in some town water supplies) will damage or even kill plants. High levels can be removed by filtering through organic material such as straw.

Distilled salt water is suitable for hydroponics if obtained from solar distillation units (NB: Sea water is distilled in metal stills in some parts of the world. In this situation, metals can contaminate the water at levels which are harmful to plants, though safe for human consumption).

Very alkaline water can be treated by adding sulphuric acid to correct pH. This is done before adding nutrients to make up the nutrient solution.

PROXIMITY TO MARKETS

A large part of the cost of operating a hydroponic farm is the cost of transporting produce to market.

You should consider the following:

- How close are you to the place where you will sell your produce?
- If using road transport, what is the quality of the roads?
- Does the route ever suffer traffic jams?
- Does the route ever flood?
- If using rail, how frequent is the rail service?
- Is the rail system viable for its operators and if not, is there a chance that services might be reduced?
- If using air or sea transport, how reliable and regular are the services?
- Does the produce need refrigeration or any other special treatment during transport and are those services available?
- If relying on contract services, are they dependable? Do they ever strike or break down?
- Will produce deteriorate during transport?
- Do you need to produce a truck or other transportation equipment (e.g. forklift etc)?
- What will transportation cost?

Transportation to market may vary considerably depending on the site.

Greenhouse Tomatoes

CHAPTER 3 : ALTERNATIVES

There are a bewildering number of choices to be made when deciding what type of system to use. This chapter is designed to help you choose the system that is right for you.

Water, Aggregate or Rockwool Culture

The first choice is whether to use water culture, aggregate culture or rockwool. All three are viable and used successfully with a large variety of crops in many different parts of the world.

Your choice should take into consideration the following:

- What is the cost of each and how readily available are materials in your area?
- Is rockwool made/sold locally? If not, what freight charges are involved in having it delivered?
- Is there a local source of sand or gravel which can be used, or do you need to pay high cartage costs?
- What types of plants will you grow?
- Some plants require better aeration than others. Some systems provide better aeration than others, for example NFT systems.

COMPARISON OF CULTURAL SYSTEMS

ROCKWOOL	NFT	AGGREGATE
Modules are isolated (i.e. solution runs to waste)	Modules are connected (solution recycled)	Modules may or may not be connected
Ability to easily flush out salt build up	Salts may occasionally build up on the sides of gullies, channels etc.	Nutrients may sometimes bind to aggregate media eg. scoria, pumice
Slabs are usually thrown away after one crop (suitable landfill tip site is needed)	No part of the system is thrown away	Medium is normally reused for many crops
Water:air ratio changes between irrigations	Water:air ratio remains constant	Water:air ratio changes
Excess watering is needed (15%) to ensure driest slab remains wet	Water flow may become impaired by vigorous root systems (eg. cucurbits)	Pressure needs to be high enough to provide adequate flows at the end of trickle irrigation runs
Nutrient imbalances not likely	Continual monitoring of nutrient solution needed to prevent nutrient imbalances	
Suits most crops	Suits most crops except cucurbits	Suits most crops
Popular for carnations in Australia	Popular for lettuce in Australia and the UK	

Hydroponic Media

There are three main groups of hydroponic media, based on their origins:

1. Media derived from rock or stone

2. Media derived from synthetics

3. Organic media

General Characteristics

Media is the term given to the solid material(s) used to replace soil in aggregate culture and rockwool culture.

Hydroponic media must fulfil the following criteria:

- They must be chemically inert.
- They must be chemically stable.
- They must be clean.
- They must drain sufficiently freely not to create waterlogging problems.
- They must have adequate water-holding capacity.
- They must have adequate air-holding capacity.

Also:

- Buffering capacity should be good – this is the ability of the media to resist changes in pH.
- It is preferable that cation exchange capacity is at least moderate to good.

Cation Exchange Capacity

Cations are atoms which have lost electrons. As such they are particles which have a positive charge. Many important plant nutrients occur in the nutrient solution as cations (i.e. potassium, calcium and magnesium). These particles will attach themselves to media particles which have a negative charge, hence staying in the media and being available to the plant roots for a longer period of time.

Organic matter such as peat moss, and fine particles such as clay have a lot more negative charges on their surface, hence a greater ability to hold cations (higher cation exchange capacity) than larger sand or gravel particles. Media with a very low cation exchange capacity will require more frequent application of nutrients than ones with a higher cation exchange capacity. When nutrient solution is applied to a medium with a low cation exchange capacity but high water-holding capacity, the medium might remain moist, but the nutrients do not remain in it after the irrigation as well as in a medium with a high cation exchange capacity.

MEDIA DERIVED FROM ROCK OR STONE

Vermiculite

This is a mineral derived from mica mined in South Africa and the USA. The mined mineral is treated in a number of ways including heating at temperatures of nearly 2000 degrees F to obtain the product used in hydroponics. Technically vermiculate is hydrated magnesium aluminium iron silicate.

Vermiculite is very light and spongy in appearance, though different grades of vermiculite have different weights. This mineral retains air, water and nutrients very well, making it ideal for hydroponics. The pH of vermiculite is sometimes slightly acidic or slightly alkaline, although rarely enough to pose much of a problem with growth. Its pH buffering capacity is very good (i.e. it resists changes in pH) and it has a relatively high cation exchange capacity.

Vermiculite needs to be mixed with other media to get the best results. Even though it retains air well, it can retain too much water for many plants. If used on its own it can after a year or so turn puggy (i.e. the structure can collapse). However, mixed with gravel or sand (no more than 40 to 50% vermiculite) it retains its structure, and drainage is improved to make it a more ideal medium.

Vermiculite is also used in the building industry for insulation. You should only use horticultural vermiculite in hydroponics. This is available in different grades:

No.1 – 5 to 8mm in diameter

No.2 – 3 to 4mm in diameter (this is the standard grade)

No.3 – 1 to 2mm in diameter

No.4 – 0.75 to 1mm in diameter (used only in seed germination)

Perlite

Perlite is, like vermiculite, a processed mineral. It has excellent water-holding properties but is less spongy and better drained than vermiculite. Perlite is made from a silicaceous volcanic rock treated at temperatures of 1400 degrees F to form sponge-like balls. Perlite is often used by itself or in a 50/50 mixture with vermiculite (this type of mix can become too wet in some situations though). Perlite can be neutral or slightly acid. It has poor pH buffering capacity and no cation exchange capacity.

As it is predominantly white, algal growth may easily occur on perlite, and while this does not harm the plants it can clog up pipes etc in a recirculating system. Perlite is excellent for plant propagation purposes. It can be expensive. Like vermiculite it is relatively lightweight.

Sand

Granitic or silica-type sands should be used. Calcareous sands are very alkaline and unsuited to plant growth. Beach sand is not suitable because of the high levels of salt in it. Some sands have a lot of dust or other fine material in them when purchased and these need to be washed out before it is used.

The best sand is the coarse granitic sand used by nurserymen for plant propagation and in fish aquariums. By itself sand will need frequent, if not constant flow of irrigation to prevent the plants drying out. It is often mixed with other water-retaining materials though to obtain a balanced medium.

Gravel

Gravel is much the same as sand, only varying in particle size. Gravel particles are generally 2 to 15 mm in diameter, whereas sand particles are smaller, but still gritty to feel. Sand will hold water better than gravel.

Scoria

Scoria is porous volcanic rock which can be obtained in a wide variety of grades (i.e. sizes or diameters). The physical properties of scoria are excellent, but its pH can vary greatly according to where it comes from (pH 7 to 10). The cost of scoria is usually dependent on the distance it has to be transported. If you are close to a scoria quarry it can be cheap; if you are some distance away it can be expensive.

Pumice

This is a silicaceous volcanic rock, which is crushed and screened before use. Its properties are very similar to perlite except that it is heavier and does not absorb water as easily. Pumice is sometimes mixed with peat and sand to make a hydroponic medium.

Rockwool

Rockwool is made from heating rock to a molten state and spinning it into fine fibres to create a spongy, fibrous material which is used both for insulation (in the building industry) and in horticulture. Horticultural rockwool is processed differently from insulation rockwool. You should not use the insulation material in horticulture.

Horticultural rockwool is available in a loose fibre form (not unlike cotton wool or fleece), or in preformed slabs of varying shapes and depths. Rockwool slabs are more than 90% air space and so have the ability to hold large amounts of water while still retaining an extremely good level of aeration. This characteristic makes rockwool one of the most popular and commonly used media in commercial hydroponics in Australia, the Netherlands and several other countries.

Rockwool has no cation exchange capacity and very little effect on pH (i.e. the pH of nutrient solution determines the pH of the root zone; the rockwool has virtually no effect).

Expanded Clay

Also called LECA (light expanded clay aggregate), this material is made by blending and bloating clay in rotary kilns. The material looks a little like hard terracotta balls. It has a low air-filled porosity and a higher water holding capacity.

Granitic Sand, suitabler for aggregate culture

MEDIA DERIVED FROM SYNTHETIC MATERIALS

Sponge Foams

Sponge-like materials are used increasingly for propagation (cuttings) in some parts of the world (e.g. Florida). The same materials have been used successfully in hydroponic culture. Foams are used commercially in hydroponics in the Netherlands and Canada. They are generally expensive.

Expanded Plastics

These materials are inert and in many cases relatively inexpensive. Their major disadvantages are:

- They do not retain moisture or nutrients very well.
- They are very lightweight and when mixed with other materials, often separate out (or float) to the top (after a couple of months use, what was originally a mix will end up as a layer of the expanded plastic on top of the rest of the media).
- They provide virtually no support for the plant (trellis is vital).

When used by themselves in a constant flow irrigation (automatic watering) situation, these materials can sometimes be quite successful.

Examples include polystyrene (beanbag) balls, hygropor (a mix of ureaformaldehyde and polystyrol). Ureaformaldehyde releases nitrogen slowly into solution through slow decomposition. If it is used for long periods, plants can be harmed by formaldehyde residues.

ORGANIC MEDIA

Sawdust

Sawdust has been used extensively in commercial hydroponics in British Columbia and Canada, mainly because of its availability.

Hardwood sawdusts (e.g. from eucalypts) should be composted before use. Some softwood sawdusts should never be used because they contain highly toxic chemicals. *Pinus radiata* sawdust has been successful for short-term growing without composting (e.g. for propagation but not for growing a six-month crop).

Sawdust will undergo decomposition while the crop is growing if not composted first, and throughout that process the bacteria will draw on nitrogen from the nutrient solution leaving insufficient quantities for the plants.

Coarse sawdusts have been used successfully in potting soils in Australia, and should work in hydroponics. Fine sawdusts are preferred by the hydroponic growers in Canada, though fine sawdusts have caused problems when used in potting mixes in Australia. Cation exchange capacity is good, but not as high as in peat.

Peat moss

Peat moss is dug from swampy ground in cool temperate climates. It is the partially decomposed remains of plants (mainly mosses and sedges). The specific characteristics of peat can vary from one deposit to another though the following generalisations can be made:

- Peat has a high water-holding capacity.
- Sphagnum peats generally have better aeration when wet than sedge peats.
- They are not totally free of nutrients. Some peats have a lot more mineral salts in them than others
- Black peat, which is more highly decomposed, is not suitable for hydroponics at all.
- Peat is always acidic (sometimes as low as 4.0).
- All peats have a high pH buffering capacity.
- They have a high cation exchange capacity.
- Peat repels water when it dries out. Be careful never to allow the surface of the medium to become completely dry.

Peat is useful as an additive to hydroponic media to raise the cation exchange capacity, particularly in run-to-waste systems, though it will bring micronutrients to the system which could upset the balance of the nutrient solution.

Only coarse grade, high quality peat should be used in hydroponic culture.

Coir fibre (coconut fibre)

Coir fibre has been rapidly accepted as a high quality hydroponic growing medium and is available in a range of propagation cubes, blocks, slabs similar to rockwool, and as a loose, granular product. Coir fines should be mixed with longer fibres when used as a growing medium while fines alone are suitable for seed raising.

Coir has a high water-holding capacity and air-filled porosity and holds its structure well over time. As a growing medium it can be used for several years and sterilised between crops.

Care should be taken with some supplies of coir which may be contaminated with high levels of sodium. Hydroponic growers should always select 'sodium free' horticultural grade coir to avoid this problem.

Composted bark

The use of composed bark has become popular as a peat substitute and it provides both an excellent seed germination medium and hydroponic substrate. Bark for horticultural use is pre-composted with additional nitrogen to create a stabilised product suitable for hydroponic use. Bark is superior to peat in many cases provided the correct grade is selected. Hydroponic bark media should be composed of ground fines and coarser particles which resist packing down when in use and retain high levels of aeration.

STERILISATION

Sterilisation with either chemicals or steam may be carried out to kill all pests and diseases in a hydroponic system or greenhouse prior to planting. This would commonly be done in the following situations:

- If a new system is installed in a locality where there may be diseases or pests.
- In a newly constructed greenhouse before planting the first crop.
- Where crops have been grown in the same medium for a long period, and diseases or pests have built up in the system.

Steam Sterilisation

This is expensive if you have to buy a steam generator; however, many greenhouse installations are heated with steam. It is relatively easy to install a steam converter onto an existing boiler and run steam pipes to a greenhouse with outlet pipes at required intervals.

Aggregate beds are easily treated by simply running a pipe with outlets along its length down the centre of a bed and covering the bed with a heat resistant cover. Application of steam at 180 degrees F for half an hour will sterilise about 20cm depth of sawdust or peat, or 10cm of 75% sand 25% peat. A permanent pipe laid below the surface at the bottom of the bed will give a better penetration of steam.

A steam sterilised bed can be used the day after treatment.

Chemical Sterilisation

a) With gas

This involves pumping chemical gasses such as methyl bromide or chloropicrin into a sealed area. The area is generally covered with large plastic sheets and the gas released via a pipe or tube under the sheet. Alternatively an entire greenhouse can be sterilised if it is totally sealed from the outside.

After a predetermined period (usually a matter of days), the covers are lifted or the building is opened. The area must be aired for a period to allow chemical residues to disappear before use.

b) With liquid

Formaldehyde, sodium hypochlorite and some other liquid preparations can be used to wash through hydroponic systems and over surrounding areas to kill pests and diseases. These are easy to use and relatively inexpensive, although you must be sure to wash away any residual chemicals before introducing plants into such areas.

Scoria -porous stone has been used successfully for hydroponics

CHAPTER 4 : PLANT NUTRITION

NUTRIENT FORMULAS

A nutrient solution must contain nitrogen, phosphorus, potassium, magnesium, calcium and sulphur if plants are to make reasonable growth. These nutrients are all needed in significant quantities by all plants. Oxygen, hydrogen and carbon are also essential; however, these are obtained by the plant from air and water.

A large number of other nutrients are also needed, but in very small amounts. These minor nutrients may find their way into a nutrient solution through impurities in the water or dust particles in the air, and that may be good enough for success in an amateur hydroponic grower's garden. The commercial grower, however, is well advised to use a nutrient solution with minute amounts of these minor nutrients added.

Minor nutrients such as iron, copper, boron, manganese, zinc, cobalt and molybdenum are just as important as the major nutrients; they are just used in much smaller quantities.

PREPARING NUTRIENT SOLUTIONS

Nutrient solutions for small hydroponic systems can often be adequately prepared by adding some additional components to a standard, general fertiliser (e.g. 5 parts gypsum and 1 part Epsom salts added to 6 parts of any powdered soluble plant food such as Thrive, Aquasol or Phostrogen). Sometimes it might be necessary to add a minute amount of micronutrient. Commercial hydroponic growers need a more accurate control of the components in a nutrient solution to achieve commercial success.

A large number of different nutrient formulas have been developed for use in hydroponics. Some give better results than others, however there is no single formula that outshines all the others. The success of each formula depends on the conditions in which it is used and on which plants are being grown.

To make a nutrient solution you need to know the relative amounts of the different nutrients a plant requires. The requirement is different for different types of plants. You need to know what proportion of each chemical ingredient you are using is actually the nutrient (e.g. one chemical might contain 20% nitrogen and another chemical 45% nitrogen; you need less than half as much of the second chemical to supply the same amount of nitrogen).

You also need to know how soluble the chemicals you use are. Some chemicals need more water or more mixing than others.

Be aware of potential interactions between the chemicals you use. Some chemicals cannot be mixed with others – they react together and become something new: something you might not want in the solution, or something inert that can't be used by the plants you are growing.

ATOMIC WEIGHTS OF ELEMENTS COMMONLY USED IN HYDROPONIC NUTRIENT SOLUTIONS

ELEMENT	SYMBOL	ATOMIC WT
Boron	B	11
Calcium	Ca	40
Carbon	C	12
Chlorine	Cl	35
Cobalt	Co	59
Copper	Cu	64
Hydrogen	H	1
Iron	Fe	56
Magnesium	Mg	24
Manganese	Mn	55
Molybdenum	Mo	96
Nitrogen	N	14
Oxygen	O	16
Phosphorus	P	31
Potassium	K	39
Sodium	Na	23
Sulphur	S	32
Zinc	Zn	65

Ionisation of Nutrients in Solution

In hydroponics, ionisation is the process whereby fertiliser salts break into their individual ions when dissolved in water. This allows rapid uptake of nutrient by plant roots.

Calculating the Amount of Nutrient in a Chemical

The proportion by weight of a nutrient element in a nutrient salt can be calculated as follows:

1. Write down the chemical formula of the salt. This should be on the product label. For example: Ammonium sulphate $(NH_4)_2SO_4$
   This simply means NH_4 plus NH_4 plus SO_4
   In total then ammonium sulphate contains:
   2 nitrogen atoms
   8 hydrogen atoms
   1 sulphur atom
   4 oxygen atoms

2. Look up the atomic weights of each of the elements in the nutrient salt and multiply them by the number of atoms of each element present in the chemical formula for that molecule.
   For example:
   Nitrogen (atomic weight = 14) 2 atoms x 14 = 28
   Hydrogen (atomic weight = 1) 8 atoms x 1 = 8
   Sulphur (atomic weight = 32) 1 atom x 32 = 32
   Oxygen (atomic weight = 16) 4 atoms x 16 = 64

3. Add up the total weights as calculated.
   For example:
   28 + 8 + 32 + 64 = 132
   The molecular weight of ammonium sulphate is therefore 132

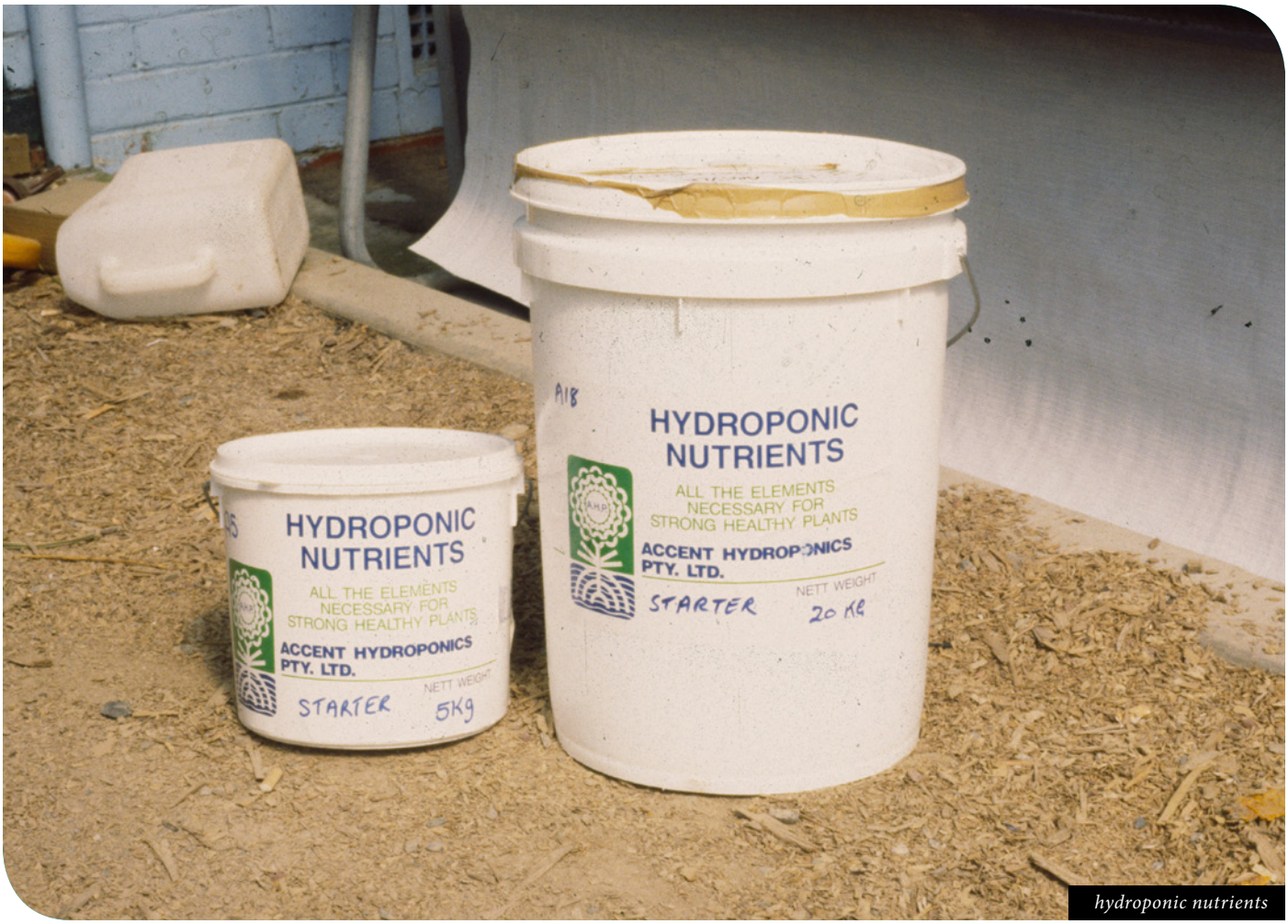
4. Take the total calculated weight of the nutrient element (i.e. in the above example this is 28 for nitrogen in ammonium sulphate) and divide this by the molecular weight of the nutrient salt (in this example that would be 132) giving 28/132 x 100/1 = 21.3%. This means that 21.3% of any quantity of ammonium sulphate is actually nitrogen.

Another example of Calculating the Amount of Nutrient in a Chemical
The formula for sulphate of potash (Potassium Sulphate) is K_2SO_4:
2 atoms of potassium… 2 x 39 =78
1 atom of sulphur… 1 x 32 = 32
4 atoms of oxygen… 4 x 16 = 64
Total = 174
Percentage of potassium = 78/174 x 100/1 = 44%

Note that many of the nutrient chemicals listed in the table in the next page contain sulphur. Sulphates are commonly used because plants tolerate large amounts of sulphur. An excess of unused sulphates around the plants' roots will be less damaging than an excess of chloride or something else.

Chemicals should be stored according to the in a dry place until you are ready to use them. Choose your fertilisers not only on the basis of the nutrients they supply but also on how easy they are to obtain and how much they cost in terms of the amount of nutrient the fertilisers supply.

The most common way of describing the content of a nutrient solution is in parts per million (ppm). Since a gram of weight is equivalent to 1 cubic centimetre of water then 1 ppm is equivalent to 1 gram of water in 1 million cubic centimetres of water (1000 litres). 1000 litres is equivalent to about 264 US gallons. If you are using US measurements you can convert to ounces by dividing grams by 28.35 and litres to gallons by multiplying litres by 0.2642.



hydroponic nutrients

AMOUNT OF CHEMICALS (IN GRAMS) USED IN MAKING 1000 LITRES OF NUTRIENT SOLUTION

CHEMICAL COMPOUND	NUTRIENT ELEMENT SUPPLIED	GRAMS TO GIVE 1 PPM IN 1000 L OF WATER	SECOND ELEMENT SUPPLIED
Ammonium sulphate	Nitrogen	4.7	
Calcium nitrate	Nitrogen	6.45	Calcium 1.36 ppm
	Calcium	4.7	Nitrogen 0.74 ppm
Potassium nitrate	Nitrogen	7.3	Potassium 2.6 ppm
	Potassium	2.8	Nitrogen 0.38 ppm
Sodium nitrate	Nitrogen	6.45	
Urea	Nitrogen	2.17	
Monopotassium phosphate	Potassium	3.53	Phosphorus 0.8 ppm
	Phosphorus	4.45	Potassium 1.26 ppm
Triple superphosphate	Phosphorus	4.78	Calcium 0.6 ppm
Calcium sulphate (gypsum)	Calcium	4.8	
Boric acid	Boron	5.64	
Copper sulphate	Copper	3.91	
Ferrous sulphate	Iron	4.96	
Manganese sulphate	Manganese	4.05	
Magnesium sulphate (Epsom salts)	Magnesium	10.25	
Molybdenum trioxide	Molybdenum	1.5	
Zinc sulphate	Zinc	4.42	

To make a solution containing, for example, 1 ppm of a particular nutrient you would need to add 1 gram of that nutrient to 1000 litres of water. To work out how much of the particular chemical you are using to supply that nutrient you would need to add to the 1000 litres of water, you need to know what percentage of the chemical is the actual nutrient. Based on the previous example this can be calculated as follows:

If the amount of nitrogen in ammonium sulphate is 23.1%, then simply adding 1 gram of ammonium sulphate to the 1000 litres of water would only add 0.231 grams (23.1% of 1 gram) to the water. To get 1 gram of nitrogen you would need to work out the ratio between the amount of ammonium sulphate and the amount of nitrogen present in the ammonium sulphate. This can be done by dividing the molecular weight of ammonium sulphate by the weight of nitrogen found in the ammonium sulphate as follows:

132/28 = 4.7

This means that to obtain 1 gram of nitrogen you would need to add 4.7 grams of ammonium sulphate to the 1000 litres. This conversion factor of 4.7 remains constant for the supply of nitrogen using ammonium sulphate as a source, so that if you wanted for example a solution containing 200 ppm of nitrogen you would simply multiply 200 x 4.7 to give 940 grams of ammonium sulphate being required to go in 1000 litres of water. This technique can be used just as simply for the other chemicals used in hydroponics stock solutions.

Preparing a Solution

A simple means of preparing a nutrient solution is as follows:

- First weigh nutrient chemicals individually
- Lay the chemicals out in separate piles and check each noting the colour of the chemical and relative sizes of the amounts, to ensure the proportions make sense and no mistakes have been made.
- Be particularly careful that no chemical component is left out or measured twice.
- Accuracy of weighing should be within plus or minus 5% (within this range the effect on plants will be negligible).
- After all this has been done, add the chemicals to the mixing tanks and stir vigorously until dissolved (the order in which the chemicals are added is unimportant, but it is extremely important to dissolve less soluble salts such as superphosphate as much as possible. There will always be some material which doesn't dissolve but this is generally not enough to be significant.
- After mixing the nutrients the pH may need adjusting (see the section on pH).
- Micronutrients should always be added after pH is adjusted in the solution.

Example solutions

The following solutions give an indication of the types of combinations of chemicals that are commonly used.

Example 1

All quantities are based on using pure water. Two concentrated stock solutions are made up as shown below:

SOLUTION 1	
To 100 litres of water add:	
Calcium nitrate	7.5kg
SOLUTION 2	
To 100 litres of water add:	
Potassium nitrate	9.00kg
Potassium dihydrogen phosphate	3.00kg
Magnesium sulphate	6.00kg
Iron chelate EDTA	300g
Manganese sulphate	40g
Borax	37g
Copper sulphate	8g
Zinc sulphate	4g
Ammonium molybdate	1g

Dilution

Each stock solution should be diluted to 1 in 100. Do not mix the concentrated stock solutions. When you are ready to apply the nutrient solutions, mix the diluted stock solutions then. This is because fertilisers containing calcium will react with any containing phosphate in a stock solution to form calcium phosphate. This will precipitate out of the solution and fall to the bottom of the tank or container holding the solution, where it forms a sludge. The majority of the calcium and phosphate in the stock solution becomes unavailable to your plants and the insoluble calcium phosphate sludge may block irrigation lines and nozzles. It is also important not to mix calcium nitrate in a stock solution with magnesium sulphate because calcium sulphate will precipitate out of the solution. The majority of other chemicals commonly used in stock solutions can be mixed together, however care should be taken when using previously untried formulations that precipitation doesn't occur.

Example 2

: Basic vegetative tomato formulation for use from seedling until fruit set with high quality (RO) water sources.

This recipe gives the amount of fertiliser salts to dissolve into two 100 litre stock solution (concentrate) tanks. A one in 100 dilution rate will give an EC of 3.0 mS/cm and TDS of 2100. (TDS is the total dissolved solids).

PART A	
Calcium Nitrate	15123 g
Potassium Nitrate	3453.7 g
Iron chelate (20%)	500 g
PART B	
Potassium nitrate	3453.7 g
MonoPotassium Phosphate	3303.4 g
Magnesium sulphate	6828 g
Manganese sulphate	80 g
Zinc sulphate	11 g
Boric acid	39 g
Copper sulphate	3.02 g
Ammonium Molybdate	1.02 g

When diluted to an EC of 3.0, will give the following nutrient levels in solution:

P = 69 ppm

K = 352 ppm

Mg = 67 ppm

Ca = 302 ppm

S = 89 ppm

Fe = 5 ppm

Mn = 1.97 ppm

Zn = 0.25 ppm

B = 0.70 ppm

Cu = 0.07 ppm

Mo = 0.05 ppm

Note: This formulation should be adjusted as the crop goes through differing levels of fruit loading to include higher ratios of potassium. Formulation is designed for a high quality, pure water source such as RO water and should be adjusted for the presence of any elements present in other water supplies. Recommended pH level for this formulation is 5.8 and EC of 3.0, season and cropping system dependent. Potassium nitrate in this formula is split between the A and B stock solution tanks to prevent problems with solubility.

Example 3

A widely used formula in the USA is one devised by Hoagland and Arnon at the University of California.

CHEMICAL	GRAMS PER 1000 LITRES OF WATER
Calcium nitrate	1181.0
Potassium nitrate	505.5
Monopotassium phosphate	136.1
Magnesium sulphate	493.0
ALTERNATIVE FORMULATION	
Calcium nitrate	1181
Potassium nitrate	505.5
Monoammonium phosphate	115.0
Magnesium sulphate	493.0
Ammonium Molybdate	1.02 g

To both formulations are added a trace element solution comprising the following:

CHEMICAL	GRAMS TO MAKE 1 LITRE OF STOCK SOLUTION
Boric acid	2.86
Manganese chloride	1.81
Zinc sulphate	0.22
Copper sulphate	0.08
Molybdic acid	0.02

This is sufficient stock to make 1000 litres of the dilute nutrient solution. An iron stock solution is also required. This should contain 1 gram of actual iron per litre of stock solution. One litre of iron stock is sufficient for 1000 litres of dilute nutrient solution.

The above stock solutions are just a few of the many solutions that have been developed for general use. Each plant, however, has different nutritional requirements, and these may vary at different stages of the plant's growth. For example when the plant is making a lot of leaf growth the nitrogen requirements are generally higher than when the plant is fruiting. Stock solutions can generally be modified to some degree to be suitable for the majority of cultivated plants; however some may require specific formulations.

Estimates of Nutrient Quantities

When you are not sure about the type and quantity of nutrients to be used then some relatively simple techniques can give you a clue:

1. The most suitable ranges of nutrient concentrations for a nutrient solution appear in the table below.

2. *Experimentation* – simply try growing a few plants of the crop you are interested in. If these show recognisable signs of nutrient deficiency or toxicity then you can adjust your nutrient solution accordingly. It is important to be careful of your solution pH as this will affect nutrient take up in the plant (see section on pH).

3. Growers who are capable of testing the nutrient status of their run-off solution can determine which nutrients are being taken up by the plants in what quantities, and adjust their nutrient solutions accordingly.

4. A rough indication of nutrient requirements can often be obtained by consideration of the type of crop you are growing. For example crops with a high percentage of leafy material are likely to have medium to high nitrogen requirements, while root crops often require moderate to high levels of phosphorus. Comparisons can often be drawn with similar growing crops.

5. Many agricultural and horticultural journals and texts provide nutrient advice and research results on particular crop species. It is often possible to get a good indication of the nutrient requirements of particular plants from these. A good example is the text Plant Analysis edited by D. J. Reuter and J. B. Robinson (Inkata Press Melbourne), which gives a strong indication of the nutrient requirements for a wide range of crop plants, based on analysis of the relationship between yields and nutrient concentrations in plant tissues.

There are now nutrient software programmes (such as the Nutron 2000+ hydroponic nutrient formulation software) which will not only provide accurate starting formulae for most commonly grown crops but also allow a grower to create a new formula and adjust this for season, stage of growth, water supply etc. This is how many inexperienced growers are managing and formulating nutrients without having to do the calculations themselves. Guessing or estimating at nutrient formulas ends up with many crop failures and often many of the 'published formulas' are not suitable for every cropping situation.

NUTRIENT ELEMENT	CONCENTRATION (MG/LITRE OR PPM)
Nitrogen (nitrate)	70 – 400
Nitrogen (ammonium)	0 – 31
Phosphorus	30 – 100
Potassium	100 – 400
Calcium	150 – 400
Magnesium	25 – 75
Iron	0.5 – 5
Boron	0.1 – 1
Zinc	0.02 – 0.2
Copper	0.1 -0.5
Manganese	0.5 – 2
Molybdenum	0.01 – 0.1

Propagation

If nutrition is needed during propagation, a weaker solution should be used, i.e. the above solutions should be diluted by a further 1 in 4.

What is pH?

pH is a measurement of the hydrogen ion concentration in a particular medium, such as water, soil, gravel etc. More simply it refers to the acidity or alkalinity of that medium. The ph is measured on a logarithmic scale ranging from 0 to 14 with 7 being considered neutral, above 7 being considered alkaline and below 7 as acid.

The pH of a medium or a nutrient solution is important to plant growth. Each particular plant has a preferred pH range in which hit grows. If a plant is subjected to a pH outside of its preferred range at the least its growth will be retarded, or it may even die. Very low pH (less than pH = 4.5) and very high pH conditions (above pH = 9) can directly damage plant roots.

Most commercially grown hydroponic species prefer a slightly acidic solution in the pH range 5.8 to 6.5. However, plants can survive in the pH range 5 to 7.5. As the pH rises from 6.5 to 7.5 or 8, some elements such as iron, manganese and phosphorus become less available and deficiency symptoms may begin to show, even though these nutrients are present in sufficient levels in the solution. Too high a pH will precipitate out iron in hydroponic solutions making it unavailable for plant uptake and causing chlorosis of the upper leaves. Some forms of iron chelate can withstand higher pH levels than others and this should be taken into consideration when formulating nutrient solutions using water supplies with naturally high pH and alkalinity. Growers should be aware that the availability of nutrients at different pH levels differs for soilless mediums than for mineral or organic soils and diagrams shown in reference books for soils are not accurate for hydroponic crops. Optimum pH levels differ for various crops with tomatoes for example preferring an optimum pH of 5.8 - 6.0, while lettuce prefers 6.0 - 6.2.

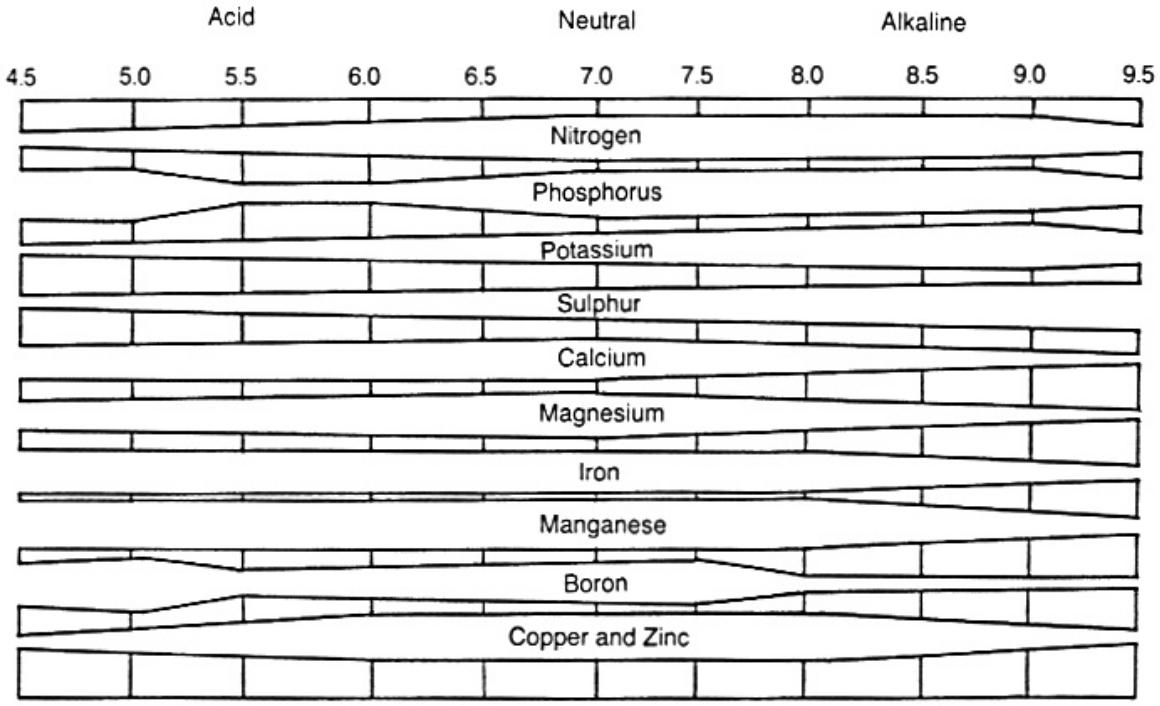
Very high and low pH values can also affect plants as follows:

1. As the pH of a medium changes so does the availability of nutrients. The majority of nutrients are most available at a pH range of 6 to 7.5. Somewhere in this range is generally considered to be the ideal for growing the majority of plants although there are plants that prefer higher or lower pH conditions. In some circumstances, particularly at very high or very low pH conditions, some nutrients may become 'locked' in the medium, becoming unavailable for plant growth. The nutrients may be there in the medium but the plant can't use them. At very low pH conditions, toxic levels of some nutrients such as manganese and aluminium may be released.

2. As the pH of some media is raised more negative charges are produced on some colloid surfaces making them capable of holding more cations. This allows some media to hold larger quantities of nutrients. The majority of hydroponic media are not affected in this way as they are basically inert materials such as sand and gravel, however media that contains clays or some of those derived from volcanic materials can be affected.

3. Like plants, microorganisms have a preferred pH range in which they thrive. Altering the pH may severely affect the populations of both beneficial and detrimental microorganisms. For example the bacteria that convert ammonium to nitrogen prefer a pH above 6. Most mycorrhizal fungi prefer a pH range between 4 and 8.

NUTRIENT AVAILABILITY AT DIFFERENT PH LEVELS



Truog's chart: Nutrient availability at different pH levels. *(From Truog. E., US Dep Agr Yearbook, 19040-47, pp. 566-576)*

Adjusting the pH

Before using a solution you should test its pH. Ready to use nutrient solution should normally have a pH between 6 and 6.5 (though for some types of plants the ideal pH is higher or lower than this). If necessary the pH can be changed as follows:

- Adding lime (or some other calcareous component) will raise the pH.
- Adding diluted sulphuric or nitric acid will lower pH.
- Ammonium salts will acidify (e.g. ammonium sulphate).
- As some nutrients are absorbed and others are left in the root environment, the pH will change.
- Careful addition of caustic soda will increase pH.

Some types of aggregate media will affect the pH of the nutrient solution and root zone, for example peat is acidic and freshly mined scoria is alkaline. If the medium is to be wet initially with nutrient solution then the pH of the solution used, for the initial wetting only, should be lowered or raised when the medium has a high or low pH.

Conductivity

Conductivity is a measure of the rate at which a small electric current flows through a solution. When there is a greater concentration of nutrients, the current will flow faster, and when there is a lower concentration, the current flows more slowly. By measuring conductivity, you can determine just how strong or weak a nutrient solution is. A conductivity meter is used to make such measurements. Conductivity can be measured in any of the following units:

- EC is short for 'electroconductivity'. EC is expressed as either millimhos per centimetre (i.e. mMho/cm), or as millisiemen per centimetre (i.e. mS/cm). Note: 1mMho/cm = 1 mS/cm.
- CF is short for 'conductivity factor'. CF is expressed on a scale of 1 to 100, where 0 stands for pure water containing no nutrient and 100 represents maximum strength of nutrient salts in solution.

Parts per million (ppm) is a measure of, the ratio of one part to one million of another. The ppm of a solution is measured using a ppm meter. This device initially takes an electrical conductivity (EC, measured in mS/cm, milliSiemens per centimeter) reading. The ppm meter uses a conversion factor (usually 1 mS/cm EC=700 ppm at 20°C or 68°F) to determine the ppm reading. EC and CF are better readings to use, as different nutrient solutions are made up of different ratios and forms of nutrient salts, each of which conducts electricity at a different rate. This means that similar solutions could yield different ppm readings. In addition, different solutions that are made up of different proportions of mineral salts can yield similar ppm readings.

EC is generally measured at 25 degrees C, and most literature and recommendations are based upon the nutrient solution being at that temperature. If the temperature of a solution is raised, the EC will increase, even though there are no extra nutrients added. If the temperature drops, the EC will decrease. It is possible to calculate the change in EC when temperature changes by multiplying the EC by a conversion factor (refer to table below).

TEMPERATURE CONVERSION FACTORS FOR DETERMINING EC AT TEMPERATURES VARYING FROM THE STANDARD OF 25 DECREES CELSIUS	
°C	CONVERSION FACTOR
15	1.247
20	1.112
22	1.064
25	1.000
27	0.960
30	0.907

Conductivity and Hydroponics

- Conductivity needs to be regularly monitored in a hydroponic system.
- Different plants have preferred conductivity levels at which they will grow their best. These levels can vary during a crop's life.
- A grower should determine the desired conductivity for the crop being grown, and any changes in that desired level from one stage of a crop to the next.
- As a solution uses nutrients, the EC will drop. When a drop is detected, nutrients should be added to the solution to bring it back to the desired level.

Water in Hydroponic Solutions

Hydroponic producers use a variety of water sources to mix their nutrient solutions, with rainwater being the most highly sought after. Many producers, however must use bore water which is harder and lower quality. In hydroponic production where nutrients are constantly recirculated, the composition of water can be a serious problem.

Water conditioning units are now available. Research on one of these conditioners, "Calclear" was carried out by SUNTEC, an independent hydroponic research organisation in New Zealand. The research determined that the Calclear units break up crystalline structures (such as calcium carbonate in hard water) into ions. In essence, they ionise the crystals that form lime scale on pipes and equipment. They can potentially do this in nutrient solutions, should any crystals have formed. The units seemed to work by increasing the uptake and distribution of water and calcium through the xylem vessels of the plants growing in the treated nutrient solution. In some way the units effected either the root cells or the development of the xylem vessels, keeping the xylem vessels unblocked. In this particular trial, the use of the Calclear conditioners reduced the occurrence of tipburn in lettuce.

Detecting Deficiencies and Toxicities

An important means of managing the nutrient requirements of your plants is the ability to recognise signs of nutrient deficiencies or toxicities, ideally as early as possible so that such problems can be rectified with minimal impact on crop yields. Such recognition can be aided by the use of simple keys such as the following one.

strawberries

KEY TO SYMPTOMS OF NUTRIENT DEFICIENCY

SYMPTOMS		DEFICIENCY
A.	Lower leaves mainly affected. The affect may occur on one part or over the whole plant	
B.	Effects appear over whole plant; lower leaves go dry; foliage turns light or dark green.	
C.	Plant light green, lower leaves yellow, drying to light brown colour, stalks short and slender if element is deficient in later growth stages	Nitrogen
CC.	Plant dark green, often develops red and purple colour, lower leaves sometimes yellow, drying to greenish brown or black	Phosphorus
BB.	Effects mostly localised; mottling or chlorosis with or without spots of dead tissue on lower leaves, little or not drying up of lower leaves	
C.	Mottled or chlorotic leaves, typically may redden, sometimes with dead spots, tips and margins turned and cupped upwards, stalks slender	Magnesium
CC.	Mottled or chlorotic leaves with large or small spots of dead tissue	
D.	Spots of dead tissue small, usually on tips and between veins, more marked at margins of leaves	Potassium
DD.	Spots spread over the whole plant, rapidly enlarging; they commonly affect areas between also; leaves thick, stalks develop shortened internodes	Zinc
AA.	Newer or bud leaves affected, symptoms localised	
B.	Terminal bud dies, following appearance of distortion at tips or base of young leaves	
C.	Young leaves of terminal bud at first hooked finally dying back at tips and margins, stalk finally dies at terminal bud	Calcium
CC.	Young leaves of terminal bud become light green at bases and finally break down here, later growth leaves become twisted, stalk finally dies back at terminal bud	Boron
BB.	Terminal bud commonly remains alive	
D.	Young leaves permanently wilted without spotting or marked chlorosis, stalk just below tip will bend over in acute deficiency	Copper
DD.	Young leaves not wilted	
E.	Dead spots uncommon, young leaves chlorotic, main veins green, yellowing can spread to older leaves	Iron
EE.	Young leaves and veins yellow	Sulphur
EEE.	Dead spots scattered over leaf, smallest veins green giving checkered effect	manganese

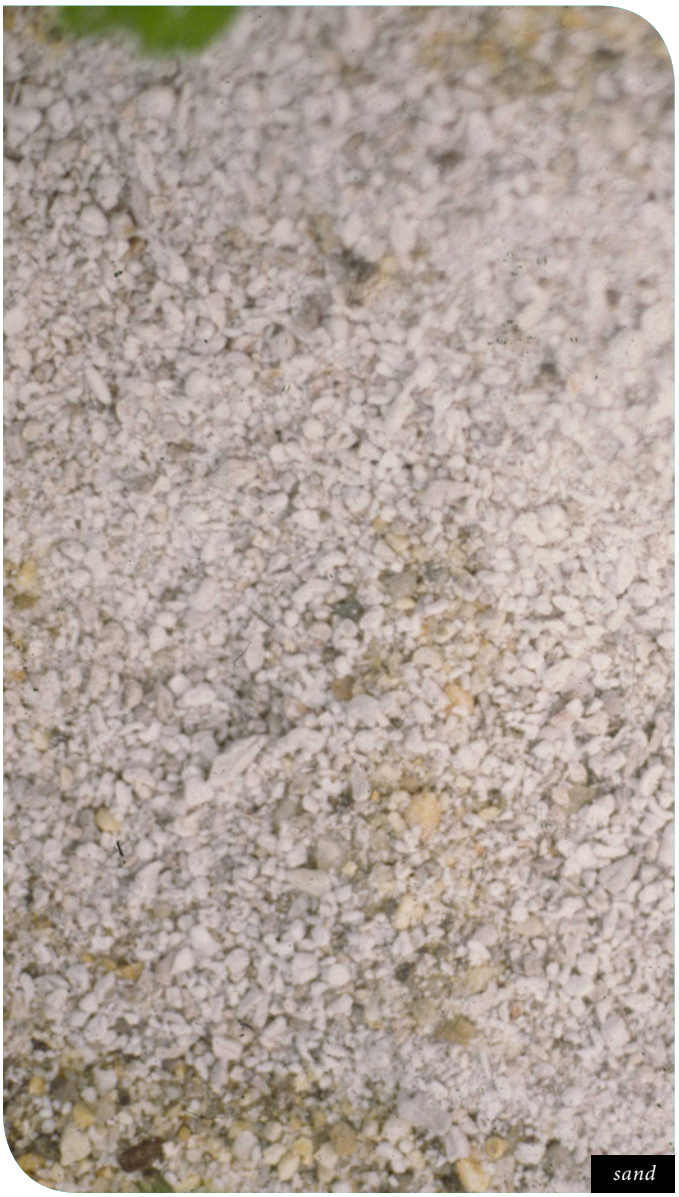
Salinity Build-up

When a plant uses a nutrient from a chemical 'salt' molecule supplied in a nutrient solution, it is in fact using only one part of that molecule. The remaining part of the molecule generally stays in the hydroponic system. It may be used by the plant, but more commonly it builds up in the system, and eventually can reach a level of concentration where it causes damage to the plant.

This is referred to as 'salt build-up' or a 'salinity' problem. Salinity problems are most common when media with a high cation exchange capacity are used, or in a closed system using the same nutrient solution for an extended period.

Salinity problems will sometimes be visible. If you see a white caking around pipes, water outlets, or on the surface of the media, this indicates the problem is reaching the danger level.

Salinity can be cured or prevented simply by leaching the salt build-up out of the system by washing it through with water. This water must of course be drained out of the system to remove unwanted salts.



sand

Soil Life and Hydroponics

In soil there are many different types of relationships which develop between plant roots and microorganisms such as bacteria and fungi. Some such relationships can be of great benefit to the plant, helping it to secure nutrients from the soil. When a plant is grown in hydroponics, free of all harmful microorganisms, it is free of the beneficial organisms also.

Some plants must have certain microorganisms, such as mycorrhizal fungi, living around their roots in order for them to grow properly. Orchids and mushrooms are two examples. Such plants will not perform in hydroponics if the root environment is very clean!

A number of microorganisms have the ability to convert atmospheric nitrogen into forms such as ammonium or nitrate which can then be utilised by plants. These microorganisms include Rhizobium bacteria, some actinomycetes and some blue-green algae. Rhizobium bacteria have a symbiotic relationship with leguminous-type plants in which they provide a source of nitrogen to the plant and receive in return other nutrients such as carbohydrates. The nitrogen is 'fixed' by the Rhizobium bacteria in nodules on the roots of the legumes and is thus directly available to the plants. Inoculation of media deficient in Rhizobium bacteria can be achieved by grinding the root nodules from mature legumes and mixing them in a small amount of water and then adding the mix to the nutrient solution.

It has been suggested by Cooper (*The ABC of NFT,* 1979, Grower Books, London) that only very low concentrations of nitrogen are required in the nutrient solution if the supply is maintained, and that it may be possible to provide an optimal balance of nitrogen-fixing plants to non-fixing plants in a cropping system, whereby nitrogen exuded from the roots of the nitrogen-fixing plants would be carried by the recirculating solution to the other plants.

Recent research into the micro organisms which rapidly colonise hydroponic systems has shown that in most cases (i.e. where continual sterilisation of the nutrient solution is not carried out) the microbes which develop are similar species to those found in the soil beneath the hydroponics system and in the surrounding area. Nutrient solutions are not free of microorganisms, but in most healthy systems, the beneficial species of microbes will out-compete and dominate any pathogenic species. If oxygen levels in the recirculating nutrients such as those in NFT drop to low levels, then pathogenic microbes often dominate and induce diseases such as Pythium and other root rots. Research into microbe populations in hydroponics has suggested maintaining healthy populations of `good' microbes is highly beneficial to plant growth and root system health and some growers inoculate their nutrient with commercial preparations of these for this reason.

Organic Hydroponics

Organically derived fertilisers such as manures are complex chemicals which require microorganisms to act upon them and break them down into simpler forms before the plant can take them in. Such fertilisers cannot be used in hydroponics unless the appropriate microorganisms are first introduced to the hydroponic environment. Hydroponics is possible with organic chemicals if the root zone is inoculated with appropriate decomposing organisms, however the commercial potential of organic hydroponics seems very uncertain in the near future – both due to the difficulty of developing a biotic system that works adequately and because the organic industry and the hydroponic industry are not directly compatible in many countries.

There are now large commercial 'organic' hydroponic growers in operations in some countries such as the USA. While organic hydroponics is certainly feasible from a technical perspective, there is still debate over whether a system that is completely soil-less, and is based on continuous product inputs, can be considered to be `organic' since the organic certification is largely based on soil health and *redesigning* the production system, rather than replacing 'conventional' inputs for 'organic' ones.

However in countries such as the USA and Canada, organic certification agencies allow the use of organically derived growing media such as coconut fibre, vermicast, compost, sawdust and ground bark. Growers often rely on bags or containers of such organically derived but soil-less growing media and feed plants on organically derived nutrient solutions consisting of several types of approved liquid fertilisers and allowable fertiliser salt inputs. Growing media is usually inoculated with vermicast or microbe solutions which allows for nutrient mineralisation in the root zone. While 'organic' hydroponic methods can produce excellent quality and high yielding crops the degree of skill required to optimise plant nutrients is high and most growers rely on the use of a consultant experienced in this area. Any grower considering organic hydroponics should first check with local organic certification authorities in their country to determine if soil-less systems are allowable under their standards. Organic produce can receive good returns if quality is high and organic certification is achieved by the grower.

The Nutritional Value of Hydroponic Produce

Marketing hydroponic produce is fairly similar to marketing produce grown in other ways. However, one avenue that is being explored to differentiate hydroponic produce from other produce is the nutritional value.

There is no conclusive evidence that produce grown hydroponically is more nutritious than produce grown by any other method, although some studies indicate that it may be possible. For example, Plant Research Technologies Inc. in California, reports the following:

- Tomatoes (Patio Pride) grown in an Aquafarm system demonstrated an average increase of 50 percent in vitamin and mineral content. Of the 14 values tested, the hydroponic tomatoes showed increases in five and decreases of 25 to 30 percent in three.
- Sweet peppers (Gypsy) grown in an Aeroflo system showed an average increase of 150 percent - increases in nine of the 14 values tested and equal to soil-grown in the remaining five. The sweet peppers tested up to 300 percent higher in vitamins B2 and B3. A literature search including US Department of Agriculture, Environmental Protection Agency, Food and Drug Administration publications, and reports from university and private industry sources on the nutritional content of soil-grown crops was used in the study.
- The hydroponic produce was also tested for heavy metals and chemical residues on the Environmental Protection Agency's priority list. None were detected.

Rick Donnan, Vice President of the Australian Hydroponics and Greenhouses Association believes that hydroponically grown produce has more of a chance of being good for consumers' health because there is no contact with the ground. This lack of physical contact reduces the risk of disease organisms contaminating the produce.

The nutritional value of hydroponic produce is still an area under research. If hydroponic produce turns out to be of a higher nutritional value, it may prove to be a useful marketing tool for commercial hydroponic growers.

Tomatoes in rockwool

parsley

CHAPTER 5 : NUTRIENT FILM TECHNIQUE (NFT) CULTURE

Nutrient Film Technique (NFT) is a method of soilless culture where plants are grown bare rooted in long narrow channels which enclose a shallow stream of nutrient solution. The nutrient solution flows continuously through the channel (being recycled from the bottom to the top end by a pump). The plant roots grow into a dense mat in the channel and the foliage sits on top, sometimes provided with support by a trellis system.

The channels are made of water-tight material such as PVC or plastic film. These are laid on a slight slope to allow the nutrient solution flow from top to bottom (supported by a rack or on a bench). The channel is enclosed as much as possible, with openings only needed for the top growth of the plants to come through.

Even though the majority of space inside the channel is air space, because it is enclosed a very high level of humidity is created in which roots can still grow (in fact this ensures adequate levels of oxygen in the root zone, which can sometimes be a problem when plants are grown in soil).

A typical NFT system thus is made up of the following components:

1. Gullies along which nutrient solution flows continuously and in which plant roots grow.
2. A catchment pipe into which the gullies discharge solution.
3. A catchment tank, in which solution collects at the bottom of the gully system.
4. A pump to draw the water from the catchment tank and return it to the top of the gully system.
5. A delivery pipe to return solution from the catchment tank to the top of the gully system.
6. Tanks containing concentrated nutrient solutions or acidic solution (which can be injected into the dilute nutrient solution as required to adjust the pH or nutrient levels).
7. Sensing devices to measure pH and EC in the nutrient solution, connected to control devices (such as solenoid valves) which release additives into the nutrient solution when required, in order to maintain a properly balanced solution.
8. Benching (or some other construction) to support the gullies and maintain the required slope.

DISADVANTAGES OF NFT CULTURE

- If the flow of nutrient solution stops, the roots will dry out and become stressed very quickly.
- In a newly planted system where the channels are exposed to strong sunlight, they can heat up faster than the root zone would heat in aggregate or rockwool. (NB: The continuous flow of solution does have a cooling effect however.)
- NFT channels can become blocked by roots of vigorous-growing plants.

TYPES OF NFT SYSTEMS

Header Tank or Direct Pumping

The nutrient solution is normally stored in a sump or catchment tank which collects the run-off from NFT channels. The nutrient solution can be delivered from the sump to the top of each channel in one of two ways:

- Directly: where it is pumped into feeder tubes which supply the top of each channel
- Via a header tank: where it is pumped into a secondary tank placed a level higher than the channels. The nutrient solution then flows via a system of delivery tubes into the channels by gravity.

The advantage of a header tank is that it will continue to operate for some time after the pump ceases to operate (if there is some problem with the pump).

Gully Construction Materials

Some materials can have a phytotoxic effect in that chemicals in the material dissolve into the flowing solution and deter plant growth. Gullies or channels have been successfully constructed from the following materials:

1. PVC house guttering.
2. Square PVC plumber's downpipe with holes cut in the top for plants.
3. Circular PVC drainage pipe with holes cut in the top for plants.
4. Corrugated fibreglass sheeting with an overlay of flat plastic.
5. Asphalt-coated wood.
6. Folded polythene film pinned at the top to make a tube.
7. Concrete formed into gullies on the surface of the ground.

Polythene Gullies

- Polythene is totally inert and causes no phytotoxic effect on plant roots.
- Heavier gauge polythene allows gullies to be reused. Lighter gauge polythene is cheaper, but must be discarded after one crop.
- In England, 600-1000 gauge polythene is used, black on one side and white on the other side. A 65 to 80 cm wide sheet is used. The sheet is laid out on the permanent surface (where levels have previously been established), with the white surface underneath. The sides are then folded up and stapled together. The top of each end is then stapled. The nutrient solution is delivered by a micro irrigation tube at the top end and unused solution collects into a return pipe at the bottom.
- Black polythene (both sides) has been used, though this will heat up the solution if exposed to the direct sunlight and can 'cook' the roots in a young crop over summer. Once the crop grows and begins to shade the plastic this problem disappears. In hot conditions, shading may be used in the interim period until the crop is large enough.
- Pre-creased gusset channel made from polythene sheet is available in some countries, including the UK. This is PVC that has already been folded into a channel shape which can be rolled out on a prepared surface and periodically joined together along the top rim through existing holes using a supplied clip.

PVC Gullies

- Rigid PVC has no phytotoxic effect on plant roots.
- Flexible PVC has at times had a phytotoxic effect on plant roots.
- Rigid white PVC plumber's pipe has often been used with holes cut out to insert plants.
- Specially designed products made from rigid PVC are available; for example, Vinidex Hydro Channel which consists of rectangular growing channels with a variety of different lids and end caps.

Concrete

Permanent channels can be formed in concrete, and covers laid over the surface with holes to insert plants in.

Concrete gully systems have been operated successfully on a commercial basis in both England and the West Indies.

Corrugated PVC or Fibre Glass

Corrugated sheet, as used in roofing, is sometimes used as a base for NFT gullies. Solution can be fed in the top and flow down to the low points of the corrugations. A second layer needs to be established above to support the plants.

Metal Gullies

Metal piping should not be used because it will corrode. The corrosion leads to impurities in the system which can upset pH and nutrient balances, clog small pipes (when flakes of metal chip off) and in some cases cause toxicity to plants.

Modified NFT

A modified form of NFT often used, involves filling the NFT channel with a very coarse aggregate such as gravel. There is still a continuous flow of nutrient solution through the gully, and with a very coarse aggregate that flow is not impaired.

Major advantages are:

- Moisture adheres to the aggregate. This increases the availability of moisture in the higher layers of the channel and should the flow of nutrient stop, the roots will be kept moist for a period until the flow can be restarted.
- Temperature fluctuations are reduced. The aggregate stops the channel heating up or cooling down so fast.
- The aggregate supplies support to the plants.

Disadvantages are:

- As roots grow through the aggregate, these can have a significant damming effect on the flow of nutrient irrespective of how coarse the aggregate particles are, particularly in longer season crops such as tomatoes.
- Removal of root systems from the aggregate is difficult and labour intensive, remaining root debris can act as a source of root pathogens for the next crop.
- Aggregate such as gravel can heat up on the surface, resulting in a rapid rate of evaporation of water from the nutrient, salt build-up and stem damage.

Solution Delivery

Normally solution is delivered as a continuous flow; but sometimes it is only delivered for a few minutes, then stopped for 15 to 60 minutes before flowing again. In the case of plants which require very good aeration, this intermittent supply may be used to increase aeration in the root zone (particularly critical in established plants where the roots system can clog the channel and slow down the water supply).

Capillary Matting

No matter how carefully constructed the base of an NFT channel is, you will still almost always get some fall from one side of the channel to the other. Capillary matting is sometimes placed on the bottom of the channel to even out the flow of solution. The solution is soaked up by the mat and spread right across the channel, preventing the solution from flowing on one side of the channel, leaving the other side dry.

The capillary mat material must be absorbent, physically stable and chemically inert. There have been cases of phytotoxicity reported through the use of inappropriate materials for capillary matting. Materials used successfully include cellulose fibre, rockwool and various artificial fibres.

Channel Width and Length

The width for a single row of plants should normally be between 10 cm and 15 cm. For a double row of plants, the channel should be 25 to 30 cm wide. Multi-channels, more than two rows wide, are also used at times (where there is no great problem with plants growing in close proximity to each other).

NFT channels should not be any longer than 15 metres, although shorter lengths have advantages in warmer climates. This is because plants in the upper parts of long channels will remove a lot of oxygen (effect on nutrient uptake is small in NFT systems) from the solution before it reaches plants in the lower sections. Dissolved oxygen (DO) levels in NFT systems have been recorded to fall from 7-8 ppm to 0 ppm along channels as short as 10 m containing a crop with high oxygen requirements such as cucumbers, zucchinis, melons, tomatoes and similar large plants. A lack of dissolved oxygen in the nutrient solution will cause wilting of plants and lower yields. When temperatures rise, a solution holds less oxygen. Also when it is warmer the plant needs more oxygen. These things combine to create an increased problem with oxygen supply in warmer nutrient solutions.

Slope

The depth of the nutrient solution in the channel should not normally be more than a few millimetres. The major part of the root mat should not be submerged in solution.

Normally a 1:150 or greater slope is required to achieve proper flow of solution where capillary matting is used on a flat bottom. If the bottom of the channel is made using corrugated sheeting, a stiff capillary mat can be laid over the top allowing a free flow of solution along the channel below. If the bottom is flat though, the flow along the bottom will be slowed by the capillary mat, hence requiring a greater slope along the channel to achieve the same flow rate.

Where a capillary mat is not used, the slope can be as little as 1:200 to 1:250. The rate at which solution is fed into the channels should be as great as is possible without increasing the depth of nutrient solution to more than a few millimetres in the channel. This can only be determined by trial and error for each situation.

Many growers now use shorter NFT channels with adjustable slope or slopes as high as 1:60 or 1:40. This allows them to maintain the flow of the nutrient solution at a sufficient rate and prevent ponding as the root mat develops and slows the flow of solution over time.

Temperature

Ideally a solution should be kept at between 18°C and 22°C for most plants. There is a danger of solutions overheating inside channels if they receive too much direct sun in the early stages of a crop. As the crop develops though, it will shade the channel and this becomes less of a problem.

Deep Flow Technique (DFT)

This modified NFT technique involves placing roots in a PVC pipe which is flooded with nutrient solution and then gravity drained. The roots are submerged in around 4-6 cm of nutrient (or 40% of the gully height) for 15 minutes. The solution is then allowed to drain to 1mm depth for the next 15 minutes.

It is important that the nutrient solution is heavily aerated, and that the roots never dry out or are flooded for too long. Aeration may be achieved by piping air bubbles through the solution in the sump. This method is used for leafy vegetables and tomato production.

Aerated Flow Technique (AFT)

AFT is a modification of DFT and involves extensive nutrient aeration. AFT aerates the solution more heavily than DFT. One way of achieving this is to bubble air up through the nutrient solution from pipes inside at the bottom of the channels.

cucumbers

NUTRITION

For many years it has been considered that all plants require around 20 nutrient elements for their growth, and some plants might require a few more. Less than ten elements are known to be used in large quantities, and these are what make up the bulk of any nutrient being fed to plants growing in NFT. The remaining nutrients are generally supplied in either tiny quantities, or not supplied at all. It is assumed that dust in the air or impurities in the system will supply these tiny quantities of minor nutrients. This is however not always the case, and minor nutrient deficiencies can have drastic effects on the crop produced (even though they are only needed in small amounts).

Research has actually found that up to 93 elements are in fact needed to maximise the flavour in fruit and vegetables. For example, potassium and magnesium are particularly important to the flavour of strawberries, though many other nutrient elements still have a contributing effect on the resulting quality.

Early research by Stoughton (1969) recommended that nutrient solutions for general use in NFT should have the following levels:

Nitrogen: 100 to 300 mg/litre

Potassium: 120 to 250 mg/litre

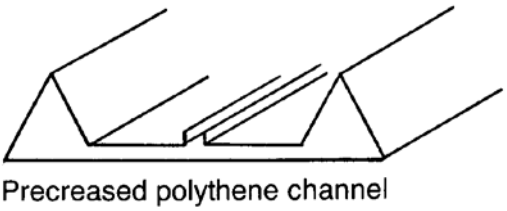
As with most growth requirements, plants will always have a relatively wide range of conditions that they can tolerate, but usually a narrower range which will produce optimum results.

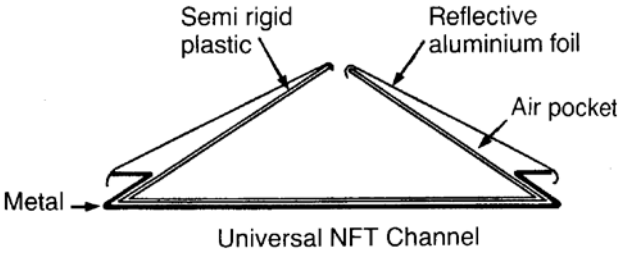
COMPARISON OF CULTURAL SYSTEMS			
Nutrient (mg/litre)	**Minimum**	**Optimum**	**Aggregate**
N	50	150-200	300
P	20	50	200
K	50	300-500	800
Ca	125	150-300	400
Mg	25	50	100
Fe	3	6	12
Mn	0.5	1	2.5
Cu	0.05	0.1	1
Zn	0.05	0.1	2.5
B	0.1	0.3-0.5	1.5
Mo	0.1	0.05	0.1
Na	-	-	250
Cl	-	-	400

Recommendations for nutrient concentration for tomatoes in NFT culture (UK Department of Agriculture)

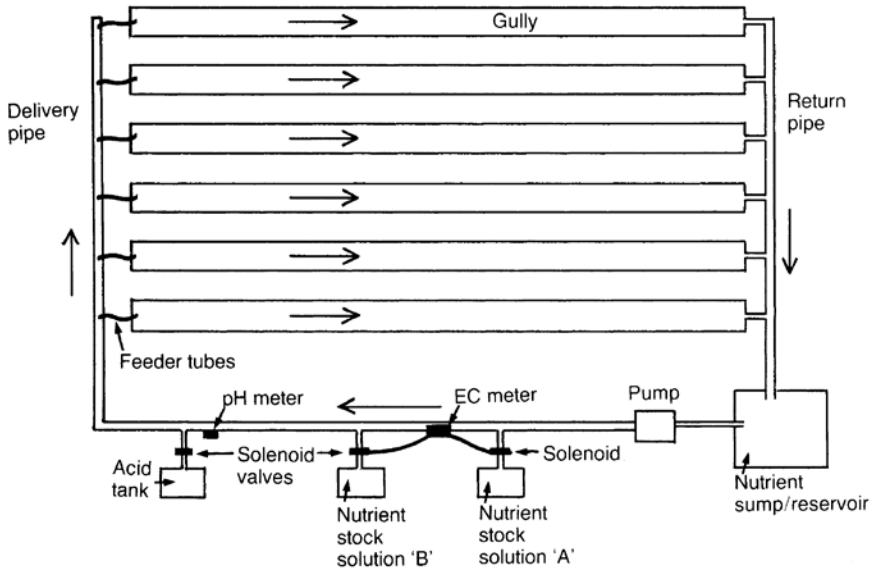
While plants in NFT can grow well at a range of nutrient levels it is generally not advised to run very low levels of major nutrients as the solution must contain a sufficient `reserve' of each element to prevent depletion. For this reason nutrient levels are maintained at much higher levels than the plant requires but this allows for depletion of certain elements over time which are not typically measured on a daily or weekly basis. If levels as low as 3.7 mg/litre of potassium were continually run in NFT, plant growth would most likely be acceptable. In reality, the potassium initially applied at 3.7 mg/litre would be extracted by the plants within a day and the solution would become depleted. If levels of potassium of 150ppm are run, it would take some time of continual use for depletion to occur, giving a safeguard against nutrient deficiencies. Care should be taken with interpretation of data from nutrient uptake trials as they often do not apply to a practical commercial situation.

African Violets on Capillary Feed Mat





Examples of NFT Channel



Design for an automated NFT System

CHAPTER 6 : ROCKWOOL CULTURE

WHAT IS ROCKWOOL?

Rockwool is a fibrous material produced by melting rock and spinning it into threads. Developed in Denmark in the late 1960s for horticultural use, it was marketed under the trade name "Grodan". Its commercial use expanded throughout the late 1970s, especially in Western Europe for the production of glasshouse vegetables and cut flowers. In Holland use of rockwool for vegetable and cut flower production expanded from 100 hectares in 1979 to 10,000 hectares in 2001.

Today rockwool is marketed under several different names including the original "Grodan". Along with NFT, rockwool systems dominate worldwide hydroponic production. Major crops grown in rockwool are tomatoes, cucumbers, carnations, gerberas, strawberries and roses.

How Rockwool is Made

Rockwool has been manufactured as an acoustic heat insulation material for over 60 years. The production technology has been extensively improved over this period, but the basic product has remained virtually unchanged.

The raw materials are natural rocks such as basalt, plus coke as the fuel. These are fed into a blast furnace through which air is blown so that the coke burns and lifts the temperature to over 1600°C. The rocks melt to form a type of lava which settles to the bottom of the furnace and is tapped off.

The stream of lava flows into a series of high speed rotors. These spin off molten droplets which lengthen into fibres and are then cooled by a blast of air. Binder is sprayed into this air stream which also carries the fibres clear of the rotors and deposits them along a production line where it is pressed, hardened, trimmed and finally cut into slabs. One manufacturing aspect of the rock-fibre mat is that the fibres orientate in a horizontal plane. This has implications that are important when the material is used for horticultural purposes.

Insulation rockwool and fibreglass are useless for horticultural purposes. However, the rockwool manufacturing process can be modified to produce a suitable horticultural product. The slabs of base material can be shaped into the specialised forms of product such as propagating blocks.

Characteristics of Rockwool

- It is very lightweight.
- Most types of rockwool are approximately 5% solid material by volume. This leaves an enormous amount of space which can be filled by air, nutrients and water.
- Generally, it cannot be over watered (there is always adequate air space).
- The ratio of water to air in the average free-draining slab is frequently two parts water to one part air.
- It takes longer to dry out than many other growth media hence the chance of water stress is reduced.
- It is sterile. If it is to be reused, e.g. slabs in a soilless system, it may be sterilised with steam or chemicals. It will withstand low pressure steam or steam/air treatment but not high temperature autoclaving which tends to break down the bonded structure.
- It has excellent insulation characteristics which keep the root zone from getting too hot or cold.
- The greater the depth of rockwool, the more air it will hold in proportion to water.
- Plants can continue to extract water from this medium even when it is only at 10 to 20% of its water-holding capacity. This is not so with other media. With most media, as the water is removed it becomes increasingly difficult for the remaining water to be extracted by the plant.
- If a rockwool slab does become over wet, excess water can be readily removed by tilting the slab for a short time.

rockwool

- The water content (and hence the air content) of any piece of rockwool is influenced by the thickness of the material, the drainage characteristics of the surface upon which it stands, and the method of watering. For example, a 75 mm thick rockwool slab standing on polythene holds an average of 80% water and 17% air. The water content also varies through the thickness of the slab, starting from very wet at the base and getting drier with increasing height. The water in the rockwool is also only lightly bound, so is readily available to the plant.
- It is chemically inert (except that is has a very small effect on pH).
- It doesn't affect the composition of nutrient formulae.
- It doesn't impede the availability of nutrients from solution at all.
- Cation exchange capacity is effectively zero and the material will not absorb or exchange nutrient ions from solution. One effect is that the material can be leached clean of any solution it contains.
- Biodegradability – rockwool is a bonded form of natural rock fibres. Although it can be physically broken down by expanding roots or by mechanical action, it is not biodegradable. It can easily be incorporated into the soil after use, where it should improve aeration and drainage.
- Rockwool has no long-term pH buffer capacity, however, when nutrient solution is first added there may be an initial small rise in pH. The rate and degree of reaction are dependent upon the pH and buffer capacity of the solution used to wet the rockwool.

Types of Rockwool

Rockwool can be obtained as preformed slabs or as loose flock or fibre material.

Slabs

Slabs can vary in width, length and depth. Most manufacturers offer a variety of sizes.

- Small slabs partially cut into tiny cubes are used for propagation. Seeds or cuttings struck in these blocks can be transferred to larger growing slabs or blocks by carefully separating the individual cubes and then planting them on or into the larger slabs.
- Deeper slabs are commonly used to grow plants which have a greater need for aeration, and perhaps a preference for drier conditions.
- Shallower slabs may be used for plants requiring more water.

Rockwool slabs are used for commercial production of a large variety of horticultural crops in different parts of the world. Some of the more important rockwool slab grown crops are:

1. Course grade absorbent:
   Growing: cymbidium orchids.
   Propagating: cucumber seeds.

2. Medium grade absorbent:
   Growing: begonias.
   Propagating: tomatoes, cucumbers.

3. Fine grade absorbent:
   Growing: cucumbers, melons, lettuce and tomatoes.
   Propagating: finer seeds and cuttings.

4. 50% medium absorbent with 50% medium non-absorbent:
   Growing: gerberas, freesias, anthuriums and cymbidium orchids.

Flock (i.e. loose rockwool, or granulate rockwool)

Flock can be produced either in a form which is water absorbent or a form which repels water. It can also be obtained as coarse, medium or fine granules.

- Coarse flock has a greater water-holding capacity than fine flock.
- Flock can be used as a medium in itself, or alternatively, mixed with some other material.
- Absorbent types are used by themselves, but water-repellent flock is generally mixed with other materials to improve the structural characteristics.
- Coarser grades of absorbent flock are more commonly used in hydroponic beds. Finer grades are used in propagation.

Problems with Rockwool

Algae can grow on the surface of rockwool. This generally does not affect the crop, but over an extended period of time may lead to an impermeable layer developing which can stop water from penetrating the slab. Slabs are frequently wrapped in white, grey or black plastic to stop light. Without light, algae will not grow.

Slabs which are on an angle will collect nutrient solution more at the lowest point. The high end of such slabs will retain less nutrient solution than the low end. The low end can develop a waterlogged space, and the high end a dry space. As such the best space for plant growth may only be in the centre of the slab, rather than across the entire slab.

If a sloping slab has nutrient solution applied to the centre, residual salt can accumulate on the high side of the slab.

A major environmental problem with rockwool for commercial production is disposal of the media after use. Rockwool does not break down or decompose, which poses a problem for disposal as it cannot be composted or recycled in the way that organic growing media can. Most waste rockwool slabs go to landfill, at an expense to the grower. Some growers have successfully shredded waste slabs and incorporated them into cropping soil or growing mixes, but any disposal option has an expense involved.

rockwool

SYSTEM OPTIONS FOR ROCKWOOL CULTURE

Whether in blocks, a slab, or flock, rockwool is normally better wrapped or contained. It may be purchased as a block or slab wrapped in plastic film; or it may be placed into a container such as a tray or gutter. It has also been successfully used to fill trays and pots.

Generally, the base of the rockwool should always be relatively flat to avoid uneven distribution of nutrient solution which creates wet and dry spots. Heating is sometimes installed under rockwool (e.g. electric or hot water pipe).

Nutrient solution can be applied either to the top end of a system and allowed to filter through the entire system (as with NFT) or applied to each unit in the system through nozzles or drippers (eg. Each plant, slab, bed or pot). Applying solution to each unit tends to distribute the solution more evenly.

Recirculating nutrients is an option with rockwool systems, although it is mostly impractical. There are some exceptions, however. For instance, roses have been grown in a slightly sloping gully filled with rockwool where solution is fed into the top, collected at the bottom and recirculated. The time delay between irrigations is varied according to the slope, length of gully and environmental conditions.

Nutrient solution is usually allowed to either run into the soil (preferably spread evenly across the entire greenhouse) or collected into sumps.

The thickness of rockwool is a very important issue. If the slab is too thick, the top will remain very dry. If the system runs to waste, the weight of solution will push the solution at the bottom out – this means that whether the slab is very thin or very thick, you will only have the same depth of a wet zone at the bottom.

seed sowing in rockwool

Options for Rockwool System Design

There are many options for the design of rockwool systems. We will discuss the following:

- Slab Culture
- Hanging Gutter Culture
- Ebb and Flow Beds

Slab Culture

A commonly used system is where propagated plants, such as vegetable seedlings, are transferred into individual rockwool cubes (usually 75 mm) where they are grown on until well established. The cubes are then planted onto individually plastic-wrapped slabs of rockwool where cuts have been made into the plastic. Slits are also made in the plastic at the bottom of the slab to facilitate drainage. Individual drippers are placed into each cube to supply nutrient solution. The excess solution runs out into a drain. This method is almost entirely operated as an open system, though nutrients could be collected if so desired. A collection system would however add expense, which may not be commercially viable.

If there is a significant slope from slab to slab, each slab is best wrapped individually and irrigated individually. If the slope is very slight, it may be possible to wrap two or more slabs together end to end, or wrap many slabs continuously provided a waterproof barrier is placed between each pair of slabs.

Reusing rockwool slabs

If the slab hasn't been penetrated too much by an invasive root system and the previous crops weren't seriously affected by major root diseases and pests, it can be sterilised and reused. There may be a gradual loss of slab height after slabs have been steam sterilised. This must be taken into consideration when deciding if it is worthwhile reusing the slabs.

Hanging Gutter System

In the hanging gutter system, PVC gutters (similar to rain gutters) are filled with rockwool. The gutter is supported above the ground by a strong frame, and plants grow on a trellis. Because plants are off the ground, ventilation is very good, which reduces disease prospects. Nutrient solution can be fed into the gutter at the base of each plant with a dripper; any excess nutrient can be run to waste. In this system, the gutters must be very close to being level.

Ebb and Flow System

The ebb and flow system is popular because it is easy to set up and easy to use. A tank reservoir containing nutrient solution is located below a growing tray filled with rockwool. Periodically, the growing bed is flooded by a small pump on a timer to feed and water the plants. When the timer switches off, the nutrient solution drains back into the tank, which sucks oxygen into the root zone. An overflow drain adjusts the nutrient fill height and ensures the system does not overflow.

ROCKWOOL USE FOR PROPAGATION

Rockwool propagation blocks are used to provide transplants for growing not only in rockwool systems, but also in aggregate culture and NFT. They are commonly made from a 40 mm thick slab of rockwool with horizontal fibres and slits from the top to give individual blocks 40 mm square.

Deeper propagation blocks are also available for propagating plants which require better drainage (i.e. the greater depth, hence greater head of water, increases aeration in those blocks). The only problem which can occur with propagation blocks relates to them becoming too wet. This is a problem with some plant species if the blocks are not managed properly. They must be sat in or on a freely draining surface and rate of irrigations must be limited. Remember, young seedlings or cuttings are more susceptible to poor conditions than established plants.

Australian Rockwool Propagating Blocks

Parts of the following sections on propagation are from a paper presented at the Australian Correspondence School's 1985 Summer Update Conference by Mike Hartley of CSR Ltd., manufacturers of Growool in Australia.

Standard propagating blocks Each block is 35 mm square and 40 mm high, 21 blocks per sheet; 3 sheets fit into the Australian standard size propagating tray.

The horizontal-fibred blocks originally gave problems with separation and roots growing into adjacent blocks. Similar problems were observed on a visit to Europe, so an improved propagating block was developed which had vertical fibre orientation, and was grooved underneath. This type of block is less convenient to manufacture but has since proved to be very successful. Some advantages of this type of block are: roots grow vertically rather than mostly horizontally; the gap gives a degree of aerial pruning; and they are very easy to separate.

Sheet and block sizes A major advantage of rockwool propagating blocks is that they can be manufactured in sheets, with consequent convenience and time savings. However there needs to be a rational basis for selecting the sheet and block sizes. In Australia, there is a standard nursery propagation tray which, while certainly not used universally, is very widely used. Consequently, it was decided to size the propagating block to fit this tray.

The dimensions of this tray are 280 x 340 mm. After experimenting, the most conventional size of sheet was found to be one that would fit three sheets to the tray. The corresponding sheet size was set at 266 x 110 mm, and 40 mm thick. This is grooved from underneath to give three rows of 7 individual blocks, i.e. 21 blocks per sheet, or 63 blocks per tray. The blocks are each 35 x 35 mm and 40 mm high. On top of each block is a hole which is mainly an indication of the location of the block underneath. The use of a vertical fibre format makes the diameter of the cutting less critical.

These blocks are packed in lots of 100 sheets, i.e. 2100 blocks, in a carton which weighs about 10 kg.

The original release was of only one height of block, namely 40 mm. This was suitable for propagating indoor plants and vegetables. However, when used for shrubs and Australian native plants, it was less successful, unless care was taken to increase aeration by reducing water content. This could also be achieved by increasing the height of the block. Consequently, a 57 mm tall block was developed in the same 35 x 35 mm format as the standard 40 mm type. This tall block also suits long cuttings.

There was also a demand for smaller blocks giving more per tray. In this case, a product was developed with the same sheet size and 40 mm height. The sheet is subdivided into 4 rows of 9 blocks, i.e. 36 blocks per sheet, or 108 blocks per tray. The individual blocks are 25 x 25 mm x 40 mm high.

Propagation Applications

Experimentation in Australia during the early 1980s led to commercial scale propagation, initially to supply the following plants for hydroponic crops:

- Tomatoes and cucumbers from seed
- Roses and carnations from cuttings.

These were very successful but highlighted important areas for further work. The rose cuttings needed control of the water content of the blocks, and liquid feeding the vegetables showed that some commercial fertilisers are very low in iron and hence need supplementing with iron chelate. There were major problems with some single solution concentrated liquid fertilisers which precipitated calcium phosphate, leading to the development of deficiencies of both these elements.

In Australia, commercial scale nursery propagation in rockwool was initiated by propagators who were having problems either with striking or transplanting. Examples of problem plants were *Grevillea* 'Robyn Gordon' and miniature roses. Both struck very well in rockwool and transplanting losses were effectively reduced to zero, although *Grevillea* 'Robyn Gordon' required careful management of the water content in order to give a reliable strike.

Although the initial incentive for using rockwool was to solve problems, once propagators were using the system they came to realise some of the other benefits involved. One such was Andrew Burton, who then integrated rockwool into his production system to make maximum use of its benefits and consequent labour costs.

Triggered by the need to supply soilless crop growers, several major specialist carnation and chrysanthemum propagators began propagating to order in rockwool.

A grower of tube stock commenced selling plants propagated in rockwool instead of by traditional methods in tubes. The change to propagation in rockwool was unannounced, however, and there was some resistance from customers who did not know the material. He now advertises some lines as grown only in rockwool and provides most other lines in rockwool unless requested otherwise.

Horticultural rockwool was launched onto the Australian market in the early 1980s. By 1985 well over 300 different plant species had been successfully propagated in rockwool propagating blocks. The range of plants grown extends over flowers, indoor plants,

vegetables, trees, shrubs and Australian native plants. Propagation has been initiated from a range of seeds, seedlings, tissue culture plants, hardwood and softwood cuttings.

The bulk of rockwool propagation to date has been of nursery plants from cuttings. These have then been potted on into conventional potting media. A major use has been the propagation of vegetables for growing on in soil as well as soilless systems, although use with soil has been limited to date. Large seeds such as cucumber, zucchini, melon, sweet corn, legumes, etc. are normally sown direct, whereas it is usually more convenient with smaller seeded vegetables to prick out seedlings into the block. Flower plants are propagated for growing cut flower crops, also for use in the soil as well as in soilless systems. When larger 'slipper' seeds are pushed into rockwool and then watered, they have a tendency to work their way out of the block to sit on the surface, which can expose them to drying out and severe stress. This does not happen with smaller seeds, or seeds with a rough seed coat.

When plants are intended to be grown on into a soilless system, they are often propagated directly into a rockwool wrapped cube. This is often cheaper and more convenient than propagating into a block and later transplanting into a wrapped cube which has a hole to take the block.

Propagation of Micro-cuttings from Tissue Culture

There has been considerable expansion in using rockwool for deflasking tissue cultured plants. It has proved to be a very compatible medium for this purpose and, particularly in the case of micro-cuttings, it enables good support of these very small plants.

Several trial shipments of plants using rockwool as the propagating and growing medium have been exported to countries where the import of soil and similar growing media is not permitted. This use could have considerable potential, particularly because of the beneficial effect on plant quality.

Recommended Practices for Propagation Using Rockwool

Because of its properties, the following principles need to be considered when using rockwool propagating blocks:

- Use a block size suitable for the plant you are propagating.
- It is desirable to place sheets of blocks in trays with an open mesh base. Trays with a less open base restrict the drainage. Moving blocks without the support of trays can increase the damage to plant roots. N.B. Trays can be washed in antiseptic and reused many times over.
- Thoroughly saturate blocks before using them. Preferably immerse in a tub of water or alternatively, use overhead watering, but be thorough! Then allow blocks to drain for several minutes before use.
- Practice a high level of cleanliness. Though rockwool is sterile when unpacked, disease can spread easily. The propagation area, greenhouse, tools and equipment (and the propagator's hands) should always be kept clean.
- Push seed into the block only as far as is needed to just cover it and keep it from drying out. Push a cutting in just far enough to keep it standing up. The bottom of the block is the wettest and the young plant shouldn't contact that part until it has started to grow. A seed or cutting without roots on it is more likely to rot if it gets too wet.
- Don't let the blocks get too wet.
  - A deeper block will have a higher proportion of air to water.
  - A block sitting on a bed of course sand will become drier than one sitting on a surface such as concrete tor asbestos sheet.
  - You can reduce the frequency of watering.
  - Bottom heat can dry out the blocks faster than would otherwise be the case.
  - Mist or fogging systems, or propagating in bell jars or a tent to raise humidity may be necessary for some plant varieties, but these techniques can also affect moisture levels in the propagation block.
- Most irrigation methods work well with rockwool, but each one will need to be used in a different way with respect to watering frequency.
- Transplant the propagated plant as soon as roots appear in the bottom of the block. Young plants do not 'hold' as well in rockwool propagation blocks as they do in tubes.
- Transplant into larger rockwool blocks or other media without removing rockwool from around the roots of the young plant. Carefully tear a strip of blocks from the slab and remove individual blocks from the strip one by one. Do not squeeze the cubes any more than you have to. Handle gently. This minimises root damage.
- If planting into a medium other than rockwool, recognise the differences between the two media and allow for those differences. If the medium you transplant into is more water absorbent than rockwool, it can soak the moisture out of the rockwool block and dry it out before the roots begin to grow into the new medium. As most of the established roots are in the rockwool, they can be left suffering water stress. Once the roots establish into the new medium, problems such as this will disappear.

Benefits of Rockwool Propagation

Using rockwool for propagation can be of advantage to all types and sizes of nurseries. Some of the benefits to be obtained are as follows:

- A wide variety of plants strike faster in rockwool than in conventional media. This gives a quicker turnover in the nursery and hence more efficient use of propagation facilities.
- Plants propagated in rockwool can be transplanted as soon as the roots are emerging from the block, or even earlier in some circumstances. By comparison, in a tube the root system has to develop sufficiently to bind the medium together before it can be transplanted.
- Rockwool is lightweight and easier to move around the nursery
- It is easier to insert cuttings into rockwool. Softwood cuttings which need a hole to be made, for instance, can be simply pushed into rockwool.
- Transplant shock can be less than with conventional media provided the block is handled carefully. The seedling doesn't need to be pricked out and the cutting doesn't need to be bare rooted from the propagating mix and planted into a tube.
- Overall propagation cost is often less than with conventional media largely due to savings on labour costs. Time and motion studies have shown that the total time involved per plant for propagating in rockwool is less than for propagating in a conventional mix and potting into a tube. (Note: Rockwool propagation has only one stage before planting out into the hydroponic system. Conventional

methods have two stages – striking the seed or cutting, then planting into a tube or seedling tray/punnet.)

The difference in strike and germination rates and time between a conventional peat:perlite mix (1:1) and rockwool.

(Estimates based on work by staff of the Australian Correspondence Schools, and a paper presented by Mike Hartley of CSR as mentioned earlier.) These figures relate to Melbourne, Victoria.

PLANT	ROCKWOOL		PEAT:PERLITE	
	Days	%	Days	%
Aeschynanthus spp. (cuttings)	20	90	26	90
Aphelandra spp. (cuttings)	19	100	19	95
Begonia spp. (cuttings)	14	100	14-17	100
Bouganvillea (cuttings)	22	70-90	28	60-80
Carnation (seed)	2	-	7	-
Clerodendron (cuttings)	9	100	15	80
Coleus (cuttings)	5	100	7-10	100
Fittonia (cuttings)	13	100	14	100
Ficus (cuttings)	18-20	90	22-24	90
Hoya carnosa (cuttings)	10-11	100	13-17	95
Lonicera nitida (cuttings)	14	100	20-25	95
Maranta (cuttings)	13	100	18-20	100
Marigold (seed)	4	-	6-10	-
Pelargonium (seed)	6-10	100	8-15	100
Peperomia (cuttings)	22	100	19	100
Rose – miniature (cuttings)	20-30	95	25-35	95
Syngonium spp. (cuttings)	16	100	25	100

Comparison of costs of plants propagated in rockwool and conventional tube-mix (Australian cents per plant in the 1980's)

(From a talk by M. Hartley, CSR Australia)

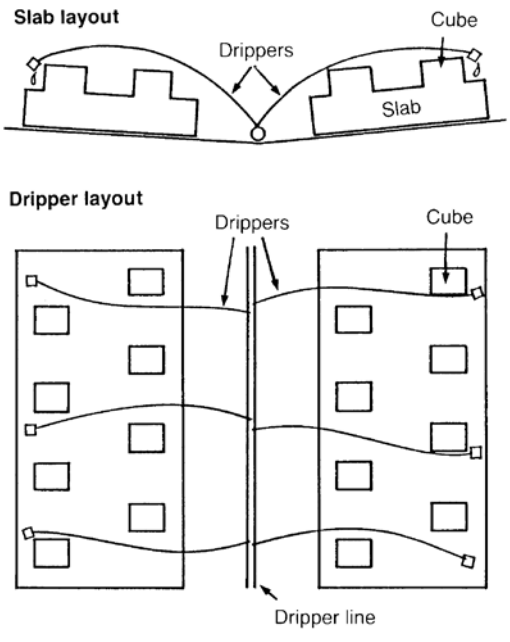
COMPONENT	ROCKWOOL	TUBE + MIX
MATERIAL	**1.6**	**1.3**
Labour (including potting and recycling tubes)	2.6	5.1
Cost of slower turnaround or propagating space	Nil	0.8
Cost of mixing and storing propagating medium	Nil	0.8
Total	**4.2**	**8.0**

These figures assume plant densities and losses are the same in Growool as in conventional sand peat mixes, which in fact is not necessarily the case. In practice there are further cost benefits with rockwool over conventional media.

Limitations Experienced in the Use of Rockwool Propagating Blocks

These limitations are cited from Australian experiences, and many have been overcome as growers become more familiar with the products and their properties.

There will obviously be cuttings which are too large for standard propagation blocks. If they are forced into the blocks these tend to split. 'Dibbing' can help, otherwise a larger block or wrapped cube should be used.



Design for a rockwool slab system

rockwool cubes

Propagating blocks are rarely suitable for holding plants for extended periods since they have rooted. If plants are fed as they need to be, then their roots will eventually grow into the adjoining blocks. This makes them difficult to separate and will cause root damage at that time. A tendency to damping off has been reported for some plants held for long periods, although in some cases additional drainage has helped. The material certainly gives optimum results if cuttings are transplanted soon after striking.

Transplanting rockwool blocks into soil may result in failure if the soil has a high draining capacity. Because the water in the rockwool is only lightly bound, it can be drained away before the plant roots have grown into the soil. Consequently care must be taken to keep the blocks moist after planting. This may require mulching and regular watering.

rockwool cutting

CHAPTER 7 : AGGREGATE CULTURE

Aggregate culture involves growing plants in a material made up of loose particles held in some type of container.

The most commonly used aggregate materials in commercial hydroponics are sand, perlite, gravel, coir (coconut fibre), ground bark, pumice, vermiculite, LECA and sawdust. Gravel differs from sand in that the particles are larger, however, sand and gravel culture are in many instances interchangeable terms. Sawdust culture is also of some commercial significance in Canada, Australia, New Zealand and South Africa.

CONTAINERS FOR AGGREGATE CULTURE

Greenhouse Floor

Here, the entire floor of a greenhouse may be covered with sand or some other aggregate. The surface below the media must first be graded to produce a slope which will give appropriate drainage to a collection point from where solution can either be recirculated or disposed of. The graded surface must be covered with a material that will keep the media clean. It may be concreted or covered with asphalt (Note: asphalt is cheaper than concrete); or covered with heavy duty PVC film laid on a bed of fine sand.

Bag Culture

Extensive use is now made of thick black polythene bags for bag culture. Such bags are UV-resistant and are available in a range of sizes for different crops. The bags are inexpensive and generally replaced between crops. They are the basis of most commercial aggregate systems – both drain to waste and recycling systems. They can be used for long-term cropping and are commonly used for the production of large ornamental plants such as palms; and for 12-18 month crops such as tomatoes and capsicums.

Various types of plastic-filled grow tubes, which are usually purchased pre-filled with aggregate such as sawdust, pumice or bark, are also used in the commercial hydroponic production of many crops.

Polystyrene Boxes

Polystyrene boxes, commonly used for packing fruit, have been used successfully by many commercial growers for holding aggregate.

Raised Beds

Generally a concrete slab is laid first, with a slope to allow drainage to a collection point at one end of the system. Walls can then be constructed from brick, stone or concrete. The bed is then filled with media.

Note: fresh concrete will affect the pH and calcium levels in your media. It is necessary for concrete to be left and washed periodically for at least several weeks before using it.

Fibreglass and Plastics

Fibreglass and rigid plastics are excellent for constructing aggregate beds, and have real value for hobby systems. Cost limits their application in commercial situations though.

Metal

Glavanised metal troughs have been successful provided they are painted to stop nutrient solution reacting with the galvanising.

Flexible Liners

Flexible polythene film or swimming pool and agricultural dam lining materials can be used to line beds built with timber, bricks, concrete or formed earth.

aggregate culture

ALTERNATIVES FOR DELIVERING NUTRIENT SOLUTION

Nutrient solution can be applied to aggregate culture either on the surface of the media, or from below the media.

Sub-surface Irrigation

If nutrient is applied from underneath, the media must normally have the ability to carry solution via capillary action upwards. This may not work for such media as coarse sand or gravel, and it will not work for many of the plastic materials.

Perlite, rockwool, vermiculite and peat all have adequate capillary action characteristics to work with sub-surface irrigation.

Sub-surface irrigation can operated in the following ways:

1. A bed is flooded, with a tap or valve on the drainage outlet being closed, and then the valve is opened and excess solution drained off.
2. Nutrient solution is fed into the top of a bed which has a sloping base below the media. A film of solution flows across the bottom of the bed, below the media. Solution moves up into the media at all points, by capillary action. Excess solution may drain into a sump and be recirculated.
3. Nutrient solution is fed into the media via wicks from a tank containing solution below the beds or containers.
4. Containers (e.g. pots or foam trays) containing media are sat in a tray (sometimes on top of capillary matting). The tray is periodically flooded with nutrient solution which rises into the containers via capillary action.

Surface Irrigation

The most popular way to supply nutrient to the surface of aggregate media is by trickle or drip irrigation.

Surface irrigation may alternatively use sprayers, however that method will wet foliage and perhaps fruit or flowers, which in turn can promote fungal diseases or lead to other types of damage to the plants.

Irrigation Frequency

The frequency of irrigation is influenced by the following characteristics of an aggregate:

Particle shape and porosity

Aggregate particles which have a regular (e.g. ball-like) shape and a smooth surface require more frequent irrigations. If the particles have crevices in their surface or are porous (i.e. water absorbent), the frequency of irrigation will be less.

Particle size

Large particles require more frequent irrigations than smaller particles.

Plant requirements and tolerances

Plants which tolerate greater variation in water levels can be irrigated heavily and left longer before a further irrigation. Plants which are less tolerant of such variations must be watered less, but more frequently to keep moisture levels within a narrower range of tolerance.

Climatic factors

Water is lost at a faster rate through evaporation in windy or hot conditions, or in systems which have water more exposed to the air.

Irrigation and Nutrition

A system which is irrigated less frequently has a lower moisture content in the media just before each irrigation than one which is irrigated more often. When the moisture content is lower, the EC or nutrient salt concentration increases. (i.e. The plant has been extracting water and useable nutrients from the media but leaving behind salt residues – the unusable parts of the nutrients. These salt residues when added to the normal nutrient solution which is left create a more concentrated solution than what was first applied. A further factor is the loss of moisture from the aggregate surface through evaporation. The water which evaporates from the aggregate surface leaves its share of the original nutrient in the media, raising the concentration further.)

Plants which are less tolerant of high EC levels are perhaps better grown in media which is suited to more frequent irrigations, and treated that way to minimise the EC creeping up between irrigations.

Sometimes nutrient solution is heated to warm the root zone and produce better growth. There is a danger if the solution is overheated. At a higher temperature, the solubility of nutrient salts, and effectively the EC, will increase. This can upset the delicate balance of the nutrient solution, and may in extreme situations cause nutrient burn to the roots of particularly susceptible plants.

Collecting Run-off

Although it is uncommon, some aggregate bag or bed systems now collect and recirculate waste nutrient. Commercial products are available for a system of nutrient collection, treatment and reuse within an aggregate system including liners, channels and collection trenches. In the majority of systems, excess nutrient solution is still collected at the lower end of an aggregate bed or at the bottom of a container and disposed of. Some of the ways this can be done are:

Flume

An open channel at the end of a bed which takes excess solution to a sump for recycling or disposal. The difficulty with a flume is that being exposed to the air, algae can grow in the channel and foreign matter such as twigs or leaves can fall in. Without a good filtration system and regular cleaning, this can lead to the water flow becoming blocked.

Collection Pipe

Here a pipe collects excess water and coveys it to the sump. Being sealed, the piped doesn't have the same problems as a flume. Do not use clear see-though pipe though, it will allow algae to grow on it.

Gravel surface and sub-surface drain

Systems which use bags or foam boxes fed with drippers often run the excess nutrient solution to waste. In such systems it is important to maintain a dry and clean surface below the container. To do this the surface must be either sealed or covered with a coarse, freely draining soil. In clay soils it is advisable to install subsurface agricultural drainage pipes to remove waste solution from the growing area.

Sculpted concrete floor

A sealed surface under beds can be sloped so that solution will drain into a collection pit (or pits). Note: be careful where you dispose of waste solution. You can build up significant salt levels at your disposal point creating very real problems with the soil in that area. If salt levels become too high even weeds will not grow, and erosion could become a problem.

THE MEDIA

There is a wide range of media that can be used for hydroponic growing. This includes vermiculite, perlite, sand gravel, scoria, pumice, rockwool, expanded clay, sponge foams, expanded plastics, sawdust, peatmoss, coir fibre, and composted bark. Some of these media are less common, so are included in Chapter Three: Alternatives. The more common media are presented below.

Gravel

Particles usually vary between 3 and 15 mm diameter. Crushed granitic rock or porous volcanic rock (e.g. scoria) are the most commonly used materials. More than 50% of the particles should be less than 1cm in diameter, and there should be no dust or fine particles less than 1mm diameter (this fine material should be washed out before use).

Calcareous rock (e.g. limestone) should not be used because it will create pH shifts. This type of rock also adds calcium and magnesium to the solution. If calcareous rock must be used, pH must be monitored and regularly adjusted; and calcium/magnesium levels must be lowered in the nutrient solution.

Fresh scoria has a high pH, but if weathered before use will drop to an acceptable level.

Fired shale has been used for some hydroponics, however due to its porous nature, salt residues tend to build up to toxic levels in the rock and are difficult to leach out after a few years. Porous rock can crumble over time and is generally unsuitable for commercial systems.

Sand

Sand culture can use particles less than 1mm in diameter; if the particles are too fine, however, the system can become waterlogged.

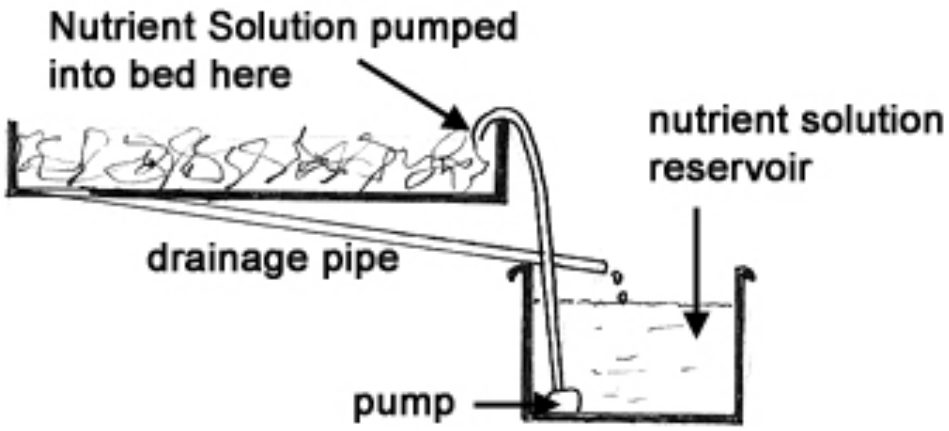
Sand should be washed to removed chemical impurities and dust particles, and screened to ensure uniform particle sizes, before being used in hydroponics.

Beach sand has been used successfully in some places (e.g. installations in the Middle East), but only after thorough washing to remove salt. If beach sand is used, it should be chemically tested after washing and before using. Silica, quartz or granitic sands are best.

It is rare that sand is calcareous, however, be aware that calcareous sands are not generally suitable for hydroponics. Note: Sand containing large amounts of shell grit may be a problem.

Additives

Perlite, peat, sawdust, vermiculite or rockwool fibre may be added to sand or gravel to increase the water-holding capacity where a crop requiring more moisture is being grown.



aggregate bed

Ausperl Perlite Grobag System

Perlite is available from various suppliers around the world, pre-wrapped in polythene 100-litre bags and 25 litre bags. As with wrapped rockwool slabs, a slit can be cut into the plastic wherever a plant is to be inserted, drainage holes cut in the bottom of the bag and nutrient solution applied through a drip irrigation system.

Ausperl Grobags are an Australian product available from Orica Australia, 1, Nicholson Street, Melbourne, VIC 3000.

Setting up the System

Ausperl bags should be used under sterile conditions to prevent soil-borne diseases contaminating the perlite. All soil should be sterilised before entering the greenhouse, surrounding weeds should be cleared and greenhouse floors should be covered with white polythene sheeting before setting up the system.

When setting up the system, the bags should be laid end to end, ideally in double rows. They are often slightly raised, using polystyrene, to allow placement of root zone heating pipes. Each bag should have a minimum of three drippers which are connected to the feeder line. Each double row should have a drainage furrow placed in the middle. The bags should be prepared in the following way:

- Cut holes in the top of the bag and insert drippers.
- Cut one or two horizontal drainage slits to a length of 4cm, usually 20mm from the base of the bag (see below). The slits should be made on the side of the drainage furrow.
- Pump nutrient slowly into the bag until the perlite is moist and the solution is draining out of the slits. The perlite will be moist enough once moisture can be squeezed out of individual grains.
- Cut holes in bags and place plants in the perlite at the same level as for ground growing.

Using the System

Perlite has a very strong capillary action which ensures that nutrients are drawn upwards from the reservoir at the base of the bag. The reservoir maintains root moisture at an optimum level, therefore the reservoir should never be allowed to dry out. Excess nutrient solution runs to waste, so the perlite never becomes too wet.

The depth of the reservoir is determined by the medium the crop is propagated in. Plants propagated in perlite, vermiculite or peat should have slits cut 20mm from the bottom of the bag. Plants propagated in rockwool blocks require an initial slit to be made 75 mm from the bottom to prevent too much water being drawn from the block. Once roots are established (usually within 2 weeks), the slits can be lowered to the normal 20mm height.

With good quality water, 10% of the solution should run to waste. EC levels should be checked regularly; if they increase above set limits more solution should be run to waste at each feed. If the solution EC still does not decrease, the EC of the input solution should be reduced (not more than 0.5 mS/cm). Flushing should only be done with dilute solution, not water, as the roots cannot tolerate the sudden change in solution concentration.

aggregate culture

CHAPTER 8 : OTHER TECHNIQUES – SELECTED EXAMPLES

WICK SYSTEM

A wick system uses a cord or fibrous piece of material which has the ability to absorb nutrient solution and raise it upwards by capillary action. Capillary action is the force which makes liquid travel upwards against the force of gravity. This is the same force which causes liquid paraffin to soak up a wick in a paraffin lamp and supply fuel from the bottom to the fire burning at the top.

A typical wick system involves the supply of nutrient solution to an aggregate bed from a reservoir of nutrient solution below the bed. Another method uses pots standing in a tray of nutrient solution. Here a wick material such as rockwool can be pushed through the drainage holes in the base of the pot so that some goes into the pot and some hangs out of the bottom. The pots are filled with a medium such as sand, and then planted. The trough is supplied with nutrient solution which soaks up the wick to moisten the sand.

BAG CULTURE

Plastic bags with drainage holes are used to hold hydroponic media. Nutrients are supplied by a trickle or drip irrigation system outlet to the top of each bag. Drainage holes at the bottom of the bag allow any excess to drain away.

In the past, bag culture nutrient solution was run to waste. These days, however there are environmental issues with simply running the solution to waste. Thus many growers are forced to collect and reuse the waste. Such bag systems can be made to work well as a recirculating system provided the nutrient is managed and sterilised where necessary. Dutch growers are legally bound to using recirculating bag and media systems, as opposed to the drain-to-waste system. Normally only one plant is grown in each bag, and bags are spaced at intervals according to the requirements of the plant variety being grown.

In a well managed and monitored bag system, the nutrient strength and application is controlled to prevent and salt build-up on the surface of the media. Leaching or flushing with water is not advised as it can cause rapid changes in the electro conductivity (EC) around the root system (osmotic potential in the root zone) which can lead to the plant taking up large volumes of water which results in problems such as fruit splitting in crops such as tomatoes. (Osmotic potential is the potential for water to move from one area of low salt concentration to an area of high concentration. E.g. Water on the surface of fruit, which has low salt concentration, moves through the fruit skin to the inside where concentration is higher, resulting in swelling and maybe cracking of the fruit).

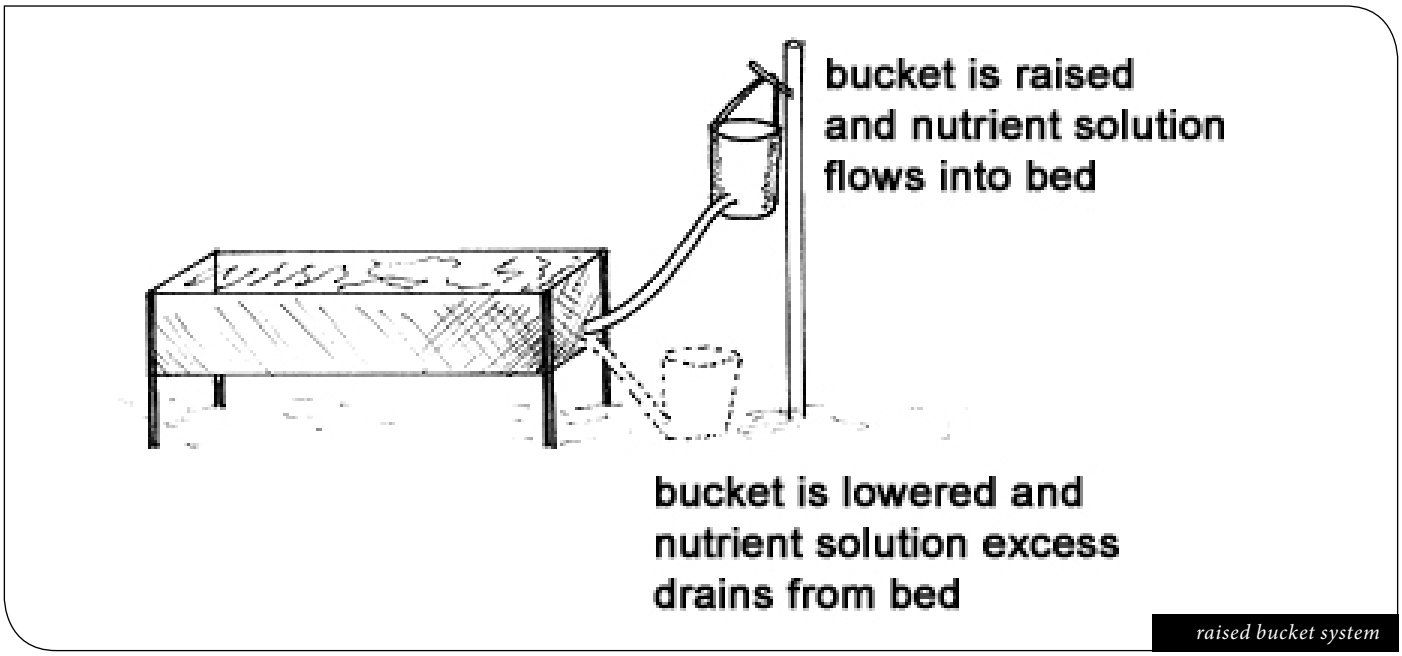
Bags must sit on top of a surface that drains freely and remains relatively dry so that roots do not grow out through the holes in the bottom of the bag. They should never sit on top of soil. In the US bags are often sat on plastic sheeting. They can also sit on coarse gravel, a sealed surface such as asphalt or concrete, or on a couple of bricks.

Bag culture is used commercially in many countries including parts of North America. The major advantage of this technique is its establishment cost. It is perhaps one of the least expensive methods to set up.

Dutch Bucket System

Also known as the Bato system, this system was developed in Holland, and is used to grow a range of plants including commercial tomato production in the US and other countries. The system is based on a series of media-filled planters (Dutch buckets), each fed by an emitter joined to a main supply line which is connected to a reservoir filled with nutrient solution.

The nutrient solution drains through the medium and any excess is drained from the buckets to the central PVC return pipe to be recirculated. Suitable media for this system include perlite, rockwool cubes, vermiculite and coir.



raised bucket system

Column Culture

This involves growing plants in vertical tubes with slits or holes cut in the sides for plants to grow through. Nutrient solution is applied to the top and allowed to filter through the medium to the bottom from where it is either run to waste or collected and recirculated.

The principal advantage is more plants can be grown in a specified area. However, there are two disadvantages of growing plants in column culture. The first is that there is a lack of light reaching the lower layers of the system – this has been noted in many vertical strawberry systems. The second is the effect of gravity which can result in lower sections of the medium being wetter (due to the weight of water above). This system is generally not used for commercial growing. Where it is, drainage and ample light are key factors in the success of the system.

Luwasa

Luwasa is a European company which produces pots fed by capillary action via a store of nutrient solution held in a reservoir below the medium. The Luwasa system is sold as a kit, with a decorative plastic pot and built-in reservoir, a pack of aggregate (expanded clay), a supply of nutrients and instructions.

The system has some applications for commercial interior plantscaping, but is not appropriate for crop production.

quality woodchip

SAWDUST CULTURE

Sawdust culture is a hydroponic method practiced by growers on a commercial scale in Canada, the USA, New Zealand, Australia and other countries where sawdust is cheap and of reasonable quality when fresh.

In these areas sawdust culture is practiced in greenhouse growing, either using beds or bag culture. Common wood sources have been *Pseudotsuga menziesii* (Douglas fir), *Tsuga heterophylla* (Western hemlock) and *Pinus radiata* (Radiata Pine). *Thuja plicata* sawdust is toxic and should not be used.

Beds are commonly built as follows:

1. The ground surface is sculpted to form a channel with a slope along its length and a 'U' or 'V' shape in cross section.
2. Timber slabs are fixed on the edges of the depression.
3. Plastic sheet (or something similar) is laid into the pit and fixed to the tops of the timber walls.
4. A 5 cm drainage pipe is run along the length of the pit/bed on top of the plastic.
5. The pit is then filled with sawdust to a depth of 20-30 cm.

Because sawdust has a good cation exchange capacity, nutrient solution has been supplied in a rather unconventional way. Before filling the bed with sawdust, the nutrient is mixed into the sawdust. After that the crop is irrigated with a different nutrient formulation, supplying only nitrogen and potassium. Sufficient micronutrients, calcium, phosphorus and magnesium remain in the sawdust to supply the crop's needs until harvest. Alternatively, nutrient can be applied as with other hydroponic systems – i.e. a full nutrient solution with every irrigation.

There is a real danger of salt build-up to toxic levels in sawdust culture. Conductivity (EC) readings need to be taken regularly, and for most crops, at levels of 4.0 mS/cm or higher, the system needs to be leached through with water.

There are other problems with sawdust culture. For example, sawdust is organic and is used unsterilised. This means that it will start to break down over time. Typically, sawdust in hydroponics first breaks down in the base of the growing bag or bed, where the grower is not aware of the problem. This area becomes saturated as the decomposing material loses its open structure and oxygen depletion occurs. This in turn often causes some degree of root die back in the base of the container and the effect on the crop can range from wilting due to a lack of oxygen, to mineral deficiencies as the plant is unable to take up sufficient nutrients due to stress in the root zone. Other problems include fruit and flower drop.

AEROPONICS

by Keith Maxwell, MSc Agr., JP
World Councillor and Aust. Rep ISOSC

The International Society for Soilless Culture in their classification of systems and methods of soilless culture (Steiner, A.A. 1976) defined aeroponics as 'The system where the roots are continuously or discontinuously in an environment saturated with fine drops (a mist or aerosol) of nutrient solution'.

Many people, worldwide, consider the future of successful crop production lies in a universal cropping system which can be used efficiently. Perhaps aeroponics is the answer? This type of culture is widely used in laboratory studies in plant physiology because of the unique opportunities for studying plant growth and development.

Practical applications in the field have not been commercially demonstrated, except on a very limited scale in Italy and Israel. Complexity of design, costs, and maintenance requirements have been considered to the primary factors against wider acceptance compared to other systems.

Many researchers consider that only 'true hydroponics' (that is, using bare-rooted plants) gives the grower full control over the root parameters and thereby a possibility of optimising the growth of plants compared to solid substrate culture.

Aeroponic systems differ from other hydroponic systems in two main ways. Firstly no inert medium is required and secondly the nutrient solution is provided by direct sprinkling to the roots.

The first aeroponic system was evolved at the University of Pia in Italy by Dr Massantini. This lead in the 1960s to the development of the 'colonna di coltura'. This consisted of an aeroponic pipe supporting three relatively small cultivation trays fitted with sprinklers and covered with polystyrene lids. A range of plants was grown quite successfully but it was expensive.

Technical Aspects

Aeration

The importance of an adequate supply of oxygen to plant roots, particularly in water culture, has been well established. Depletion of oxygen will have an adverse effect on cropping.

Over 50% of the dry weight of the plant is made up of oxygen. Much of it is taken up directly from the air through the leaves but an important part comes from the oxygen dissolved in the water around the roots. If this supply of oxygen is diminished or cut off the plant will die.

The only practical way in which oxygen can enter the water is by diffusion and this can be assisted by mechanical methods which increase the water surface area. In general, aeroponic misting has no problem with oxygen deficiency, but with high pressure aeroponic systems it is technically impossible to keep the atomising nozzles clean; also these systems have high energy costs to operate. Another problem is that with plants having big root systems, such as tomatoes and cucumbers, a larger and expensive 'root chamber' is needed.

In order to have a perfect exchange of oxygen, a loose root system is needed together with adequate water.

Water Supply

Any system of agriculture is limited by the quality of the water and this is especially important with hydroponics.

In general, any drinking water can be used, but brackish or very 'hard' water should be avoided. If there is any doubt a water analysis should be arranged.

The use of dam water for hydroponics is not recommended because of the commonly present *Pithium* and *Fusarium* fungi which can cause disease problems. If such water is used it must be freed from these fungi either physically through filtration or chemically.

The Schwalbach System

Today there are many hydroponic techniques available, which often makes it difficult for the grower to decide what is the best to experiment with before making the final decision. In general, with the increasing knowledge available, the systems tend to be more technical and thus expensive.

An inexpensive and technically simple method has been developed by Keith Schwalbach, in NSW, Australia. The essentials of the Schwalbach system are:

1. Water supply. The water used in Schwalbach's system came from an earth dam where there was no special provision to prevent contamination. This was the only water available and had to be used despite adverse comments in general for this type of water supply. The water was tested by the NSW Department of Agriculture and found to be suitable for hydroponics and general farm use, including livestock.

   The water was piped to a 200-litre plastic tank in which the nutrients were mixed.

2. Nutrient. A general purpose ready-mixed nutrient was used.

3. Nutrient tank. The nutrient solution was then transferred to the 200-litre plastic tank to which the circulatory pump was connected.

4. Pump. The pump used was a Mono, quarter horsepower, slow-revving pump which proved to be capable of servicing approximately 60 jets and was still able to bypass some unwanted pressure back to the drum. The desired pressure required was about 100 kpa. Each jet needs to deliver approximately 10 litres per hour. Because pumps are expensive and critical to the operation, it is recommended that a pump expert be consulted.

5. Growing benches.
   i) Bench top. The design has many desirable features. In the early stages marine plywood tops were used but found to be unsuitable. These were replaced with structural foam polypropylene benches. This type of plastic has many advantages as it is rigid, acid and alkaline resistant, tolerates a wide range of temperatures, is UV stabilised and 'food compatible'. The expected life of this plastic top compares well with other types, both because of the above properties and the thickness of 6 mm.

   The tops are curved to allow rain water to run off quickly, keeping them as dry as possible and almost eliminating nutrient dilution. The concave undersurface allows for a better trajectory of the spray and the curvature gives greater

strength. They are designed with pockets to take hoops so a mini igloo or shade cloth can be easily erected. The tops are interlocking and channelled so nutrient remains in the root chamber.

ii) Root chamber. The frame was made form 18 mm square galvanised pipe. The cladding of the root chamber was 2 metre-wide black PVC plastic sheeting.

6. Misting apparatus. The nutrient was fed off into each root chamber by a 13 mm black PVC pipe and jets were inserted in the appropriate places, preferably with a cut-off valve before each enters the chamber to facilitate servicing. The run-off nutrient gravitated back to the nutrient pump tank. The jets used were Wingfield misters RMST, capable of using 21 litres per hour at 22 psi. In the Schwalbach system the pressure was reduced to 12 to 14 psi, delivering approximately 11 litres per hour per jet. This resulted in the optimum trajectory and gave the most desirable spray, and also allowed more jets to be serviced by an individual pump.

7. Growing routine. Healthy seedlings with their small roots protruding are placed in the holes in the bench tops. If extreme weather is expected and appropriate cover could be drawn over the hoops of the mini igloo to improve the micro environment at very minimum cost. Within a day or two the all-important healthy 'water roots' will have developed, matched by an equally healthy top growth.

Plants can easily be relocated at any stage of their growth or left until the root becomes too extensive.

A characteristic of the aeroponic system is the astonishing growth rate of the root systems and the crops. For example, lettuce roots have been measured at 400 mm length after 21 days, 700 mm after 35 days and, at maturity, 42 days, measured in excess of 1000 mm. Tomato roots measured more than 2 m after 74 days.

Other observations made by Schwalbach which illustrate the success of this rather simple system include lettuce variety Imperial which, at maturity, measured 60-69 cm across the outer leaves and 23-26 cm across the very firm heart. Another example was the egg-shaped type of tomato which yielded more than 20 kg of good quality fruit during its 28 weeks growth cycle. Other vegetables grown successfully include parsley, silverbeet, celery, cabbage, Blue Lake stringless beans, strawberries, Mignonette and other fancy lettuce. As an experiment miniature watermelons and rockmelons and a few species of flowers all grew well.

Despite using dam water, a range of healthy, good quality vegetables were produced using Schwalbach's system. The growth cycles, in general, were much shorter than for similar crops grown in soil.

aeroponics

Lettuce in NFT system

RAFT SYSTEM

Raft systems are popular for the commercial production of lettuce, salad crops and herbs that do not require much support. In this system, plants are grown on a floating raft that rests on the surface of a shallow tank filled with aerated nutrient solution. The raft is commonly made from polystyrene foam sheets, with holes drilled through the sheets to allow the roots to dangle in the aerated solution.

The system is well suited to outdoor production in mild climates or covered by simple cloches or crop covers.

SELF WATERING POTS

Planter Technology's container irrigation system consists of self watering pots with an innovative design to regulate water supply to the plant root-zone. The pots consist of a reservoir and self-irrigating apertures that supply water directly to the plant root zone. Water supply is regulated by a vacuum-sensor that precisely monitors the soil moisture level.

These self-irrigating pots are suitable for all kinds of potted plants, and can be used for home hydroponics systems. Indoor and outdoor models are available, as well as kits to convert existing planter pots to vacuum-sensor self irrigating systems.

The Planters are distributed in Australia and New Zealand by A2Z Planter Technology, 48 Clagiraba Road, Clagiraba QLD 4211, Australia. For more information, go to

www.a2zplantertechnology.com.

The pots are manufactured by Planter Technology Inc, 30681 Huntwood Ave, Hayward Ave, Hayward, California 94544, United States. For more information, go to

www.plantertechnology.com

AUTOPOT SYSTEM

By Andrew McIntyre

There are a variety of Autopot hydroponic growing units available, all generically referred to as Autopot systems®. The common component in all Autopot growing units is the Smart-valve®, a liquid level control device that controls the allocation of nutrient solution to a growing container. Invented in Australia, and originally designed for hobby growers, two Autopot systems have been adopted for commercial production by a limited number of vegetable growers both in Australia and internationally – Autopot system hydrotray units and capillary tables.

Capillary tables

The capillary table is a growing tray, covered with cotton-based capillary matting, over which lays porous weed mat. When open, the Smart-valve allows nutrient solution to run down moulded channels in the tray, from where it is absorbed by the capillary mat. Growing containers or media blocks (such as rockwool cubes) are placed on the tray, and transport of nutrient solution to the plant roots occurs by capillary action. The capillary tables can be gravity-fed nutrient solution from a tank, or pump-fed nutrient solution from an Autopot Dosing Unit. A heating board may be placed under the tray to warm the nutrient solution.

Hydrotray units

The hydrotray unit consists of a tray that fits two 10" growing containers, and a Smart-valve in a central cavity between the two growing containers. When open, the Smart-valve allows nutrient solution to fill the tray to a level of 35 mm, and transport of nutrient solution to the plant roots occurs by capillary action in the media in each growing container. Hydrotray units can be gravity-fed nutrient solution from a tank, or in a commercial situation, any number of hydrotray units could be pump-fed nutrient solution from an Autopot Dosing Unit.

Elmac Hydroponics, a commercial hydroponic farm in Australia used capillary tables to grow seedling cherry and table tomato plants, which were later transplanted into Autopot system hydrotrays. Seagull Group in Maldives uses capillary tables both to grow seedling vegetable plants, which are later transplanted into other production systems, and to grow lettuce through to harvest. Seagull Group also uses hydrotray units to produce a range of vegetable and herb crops including lettuce, tomato, capsicum, Chinese cabbage and basil. Autopot system hydrotray units are also used for commercial production of vegetable crops on farms in Paraguay, Mauritius and China.

The Smart-valve method for controlling the allocation of nutrient solution to plants makes the Autopot systems unique, because it allows the plants in each growing container to dictate their own irrigation cycle based on water demand. The Smart-valve method is also extremely water efficient because the only wastage of water in the Autopot system is through evaporation from the surface of the growing container. However, because there is no run-off of nutrient solution from the growing container, there is the potential for accumulation of nutrient salts in the growing media, as noted during tomato production in both Australia and Maldives. Each time the Smart-valve opens, any accumulated nutrient salts might be re-dissolved into the fresh nutrient solution, changing the formulation and concentration of the solution. To date, insufficient research has been carried out on determining the optimum nutrient formulations and concentrations for using the Autopot system for commercial vegetable production.

CHAPTER 9 : HYDROPONICS EQUIPMENT

IRRIGATION EQUIPMENT

Nutrient solution can be applied in many different ways to a hydroponic system. It may be fed into the top of the media via an irrigation line or into the bottom of the media via absorbent wicks. It may also be supplied by flooding and draining off the excess, or by a continuous or intermittent flow through the bottom of the root zone.

Once applied, excess nutrient can be allowed to be lost but these days most growers collect and recirculate the solution through the system.

There are no hard and fast rules, and the best method may be different in any given situation.

Pumps

Pumps are used in hydroponics for moving nutrient solution through the system. There are two main types of pump which can be used for irrigation systems:

1. Centrifugal pumps. These operate through water being forced along driving propellers which are attached to a rotating shaft. This force creates pressure as water flows out to the discharge pipes. They are usually located above the water source. Water enters the pump through a suction pipe. The pump must be primed to remove air bubbles in the suction pipe.

2. Turbine pumps. These work by water rotating a driving propeller inside a bowl which creates the water pressure. Vertical turbine pumps draw water from a water surface. Submersible turbine pumps have the motor located below the pump in a well.

Pumps which are used for fertilising are known as positive displacement pump injectors. These injectors automatically add the correct amount of nutrient solution to the main supply line during irrigation.

Pumps used in hydroponics must be:

1. Non-corrosive. If nutrient solution contacts metal parts it can corrode and block irrigation lines.

2. Reliable. Breakdowns (particularly in recirculating systems such as NFT) can result in serious crop losses.

3. Powerful. Do not even come near to overloading a pump. Always buy something a little more powerful, operating at its maximum workload, than you will need.

Dripper Systems

Drip irrigation is perhaps the most popular way of supplying nutrient solution to commercial rockwool or aggregate systems. Drip systems supply water in a steady slow trickle to the base of each plant. This ensures that each plant is receiving a uniform supply of water at the optimum levels for plant growth. It also means the system is very water efficient.

The system is based on the construction of a main supply line of PVC pipes (eg. 3-5 cm diameter) which are connected to lateral feed lines (eg. 2-2.5 cm diameter). The individual drippers are attached to 1 cm flexible polyethylene pipes which come off the feed lines. Each irrigation takes several hours, using low water pressure (100 kpa).

Microjets, which release a much larger volume of water in a shorter period of time, can be used as an alternative means of emitting solution. Drippers are prone to blockage through build-up of algae and sediments. Filters will reduce this problem, and careful management of your nutrient solutions will minimise precipitation of low solubility chemicals.

The major consideration with dripper systems is that every dripper operates at the same rate and therefore supplies equal amounts of nutrients to each plant. This should be achieved by correct layout of pumps, main and distribution lines. In situations where this is difficult to achieve, it is possible to compensate by putting in more drippers per unit area to places with reduced flow rates. Irrigation lines and drippers should be cleaned between crops using acid solutions, according to the manufacturer's suggestions.

SOLENOID VALVES

A solenoid valve is a valve which can be opened and closed by using an electric signal. A solenoid can be installed to operate as a tap connecting a tank holding nutrient solution into the irrigation line. An EC meter in the irrigation line may, for instance, determine that nutrient levels have dropped too low, and then transmit a signal opening the solenoid and releasing concentrated nutrient. As the nutrient concentration rises in the irrigation line, the EC meter detects the change and at a given point will shut off the solenoid, stopping any further release of nutrient. This is of course only one example of how a solenoid might be used in hydroponics.

NUTRIENT CONTROLLERS

Total salts concentration is determined by measuring electrical conductivity of the nutrient solution. This needs to be monitored closely as the nutrient concentration will be continually dropping due to nutrients being taken out and used by the plants growing in the system. An EC meter (electroconductivity meter) is a device which measures the flow of electricity between two electrodes. If the concentration of salts in the solution is stronger, there will be a stronger flow of electrons.

An EC controller monitors and shows the EC level in the solution at all times, and operates injection pumps which add concentrated nutrient solution to the solution in the system when the level falls.

EC will increase if temperature increases. Because of this, it is necessary to provide temperature compensation in the salinity control system. This is usually calculated on the basis of 2% per degree centigrade.

An EC controller automatically compensates for EC drop bringing it back to a predetermined level, thus maintaining optimum nutrient levels at all times.

Over a period of time, there can be build-up of unused salts (ie. parts of the nutrient solution chemicals which are not used). This can create an inappropriate EC reading which will make

it necessary to make adjustments to the setting on your EC controller. Alternatively the solution needs to be replaced with a fresh solution or the system flushed out with water.

Although EC controllers can maintain nutrient solutions for periods at optimum levels, it is advisable that chemical analysis of the nutrient solution (for nitrogen, potassium, calcium, magnesium, phosphorus and iron) also be carried out from time to time. In large commercial operations, such a chemical analysis should be undertaken at least every two weeks. Many commercial growers carry out on-site nutrient analysis with the use of portable equipment of various types, as it takes several days for most labs to return a full nutrient analysis – often too long when nutrient changes are occurring rapidly in a crop.

PH CONTROLLERS

pH (ie. the level of acidity or alkalinity) is critical to the growth of many plants. Different plants prefer to grow within different limits of pH. Most plants prefer a pH range of 5.5 to 6.5.

A pH controller is a device linked to an electrode in the catchment tank. The electrode measures the pH of the nutrient solution and relays the reading to the controller. The controller can be programmed to inject predetermined amounts of acidic or alkaline solution into the catchment tank if the pH reaches an upper or lower limit. This way, the pH of the solution can be brought back to a level which is suitable for the plants being grown.

If the nitrogen supply in the solution is predominantly potassium or calcium nitrate, the pH will rise during cropping and acid needs to be added periodically to bring the level back to something reasonable. If the pH drops below 5.0, there can be problems with corrosion of parts in the pump.

Usually nitric or phosphoric acid are used to correct high pH in nutrient solutions. They are premixed 1:10 or 1:20 with water and injected into the catchment tank as required, allowing maximum mixing to occur before the adjusted solution is delivered to the plants. A 10% solution of potassium hydroxide is used to raise pH levels.

When mixing concentrated acids, always add the acid to the water. It can be very dangerous adding the water to the acid.

pH probes need regular cleaning and calibration and most have a life limited to 12 months. pH probes are a major cause of incorrect pH readings as they have a tendency to drift and become inaccurate much more rapidly than EC probes. pH standard solutions and calibration solutions should be obtained and used weekly to check and correct pH problems.

TIME CLOCKS

These can range from simple mechanised versions to advanced programmable electronic types that are suitable for multiple operations. They can provide a simple means of automatically controlling such tasks as turning water supplies on and off and adding nutrients. The main problem with such clocks is that they operate on a particular schedule as set by the operator and don't have a monitoring capability that allows them to adjust the timing of their operation according to the plant's requirements.

COMPUTER CONTROLS

Increasingly commercial and even many amateur hydroponic growers are using computerised systems to undertake tasks such as controlling, monitoring and recording information relating to environmental conditions in the growing area, to the volume and timing of water applications and the pH and conductivity of both the input and runoff solutions. Specific hydroponic growing computer programs have been developed that can be used on inexpensive personal computers. A good program can greatly reduce the time and effort expended by the grower in obtaining the optimum growing conditions for his crops.

Specific applications that can be undertaken using computerised systems include:

1. Monitoring input solution pH so that when the required pH range, as set by the grower, is breached then a command is sent to a dispenser, such as an injector, to add an acidic or alkaline solution to the input solution to adjust the pH to the desired level.

2. Monitoring the conductivity of the input solution, particularly for recirculating systems, to either signal a warning to the grower or to send commands to either:

    a) Add more nutrients when EC readings are lower than the desired level or

    b) To flush more water through the system to leach out excess salts when EC readings are too high.

3. Monitoring and controlling, within required levels, environmental factors such as air and root zone temperatures, humidity, light intensity etc. This can be achieved via the computer controlling air vents, heaters, misting systems and other automated equipment.

4. Controlling and monitoring the frequency and volume of water application, and monitoring water runoff in run-to waste systems as a means of determining water use.

5. Providing a record of environmental conditions experienced and nutrients used in producing each crop.

Additional information such as crop yields and production times can be added manually to the computer record to provide a complete crop history for future reference.

Research in Europe and the US has also indicated the potential of such systems to monitor and control the level of individual nutrients, and that this could be extended to adjust required nutrient levels to match differing weather conditions.

polypipe joiners

SUMPS/STORAGE TANKS

Tanks are frequently too small for the system they are used in. The size of the tank depends on:

- How much water the plants uses (fast-growing crops use more)
- How much water is lost through evaporation (depends on temperature in the growing environment)
- Method of applying nutrient solution (capillary feed results in smaller losses through evaporation
- Whether you are using a closed or run-to-waste system
- Type of medium (media such as perlite or rockwool which retain a lot of moisture require less frequent irrigations than media such as coarse sand).

As a general guide:

In aggregate culture – 91 litres (20 gal) per square metre of growing area in cool climates; 136 litres (30 gal) per square metre in warm climates.

Volume should be enough to completely fill the beds one and one-third times (ie. liquid volume plus the volume of solids in the media equals the total volume of the tank plus 33%).

A tank 5450 litres (1200 gal) in size will supply a gravel bed 105 m x 0.6 m x 0.3 m deep (350 ft x 2 ft x 1 ft).

Materials for Tanks

Metal tanks (even galvanised) are not recommended. Chemicals in the nutrient solution make metal tanks more susceptible to corrosion than metal tanks which hold drinking water.

Concrete. The major disadvantage of fresh concrete is its lime content, however, weathering before use will eliminate this problem. Here are a few ideas for concrete tanks:

- A large concrete pipe turned on end and concreted in the base is a relatively inexpensive way of making a tank.
- A septic tank, or prefabricated water tank are other alternatives.

Fibreglass or plastic. A variety of prefabricated tanks are available, some designed for holding water or chemical sprays, some for other purposes. These are ideal for hydroponic systems but can be relatively expensive.

CHAPTER 10 : GREENHOUSE OPERATION

Greenhouses are used to control the growing environment – therefore they regulate plant growth. They can make the following possible:

- Growing a crop out of season
- Growing a crop faster
- Growing a crop in a locality unsuited to that crop

Hydroponic culture in a greenhouse has the added advantage that the nutrient solution does not become diluted by rain.

Though greenhouses are normally used to keep plants warmer than the outside environment, they may also be used to regulate other aspects of the environment including:

- Cooling
- Light – day length and/or intensity
- Balance of gases in the air - in particular carbon dioxide
- Exposure to pest and disease organisms

GREENHOUSES

A greenhouse is an enclosure made of material transparent/ translucent to solar radiation. The covering limits the amount of heat loss due to convective cooling by the wind, as well as reflecting some long wave radiation emitted by the crop and air (depending on the cover material). Consequently, when the sun is above the horizon, temperatures build up with heat being transferred to the air, providing significant improvement in the growth of the crop.

A greenhouse responds very rapidly to outside conditions such as changes in solar radiation levels or cooling temperatures at night. Without heating most greenhouses fall to within 1 to 2°C of the outside temperature within two hours of sunset.

Greenhouses fall into the following categories:

- Glasshouses. These have glass walls (at least in part); they are very effective, long lasting and expensive.
- Fibreglass houses. These are made from fibreglass sheets; they are cheaper, are not as well as insulated as glasshouses, and have a medium lifespan.
- Coreflute/solar sheet houses. These are medium cost, have a medium lifespan (15 years plus), and provide more effective temperature control than PVC or fibreglass houses.
- PVC film (polythene houses). These are made from polythene film, normally over a metal framework (usually a tunnel). They are very cheap but last only a few years before requiring cover replacement. Insulation is poorer than other coverings.

Other equipment used for environmental control in growing beds:

- Hotbeds - Heat is provided in the base of a bed (box arrangement) by means of electric heating cables, hot water or steam pipes, or hot air flues. The bed needs to have drainage outlets and be made from a material which will not rot (ie. brick, concrete, treated timber, etc). An ideal size is 1 m x 2 m (3 ft x 6ft). The hotbed is filled with 8-10cm (3-4 inches) of coarse propagating sand or perlite.
- Coldframes - A coldframe is similar to a hotbed except it is not heated and has a cover/top made from glass, plastic, fibreglass or similar material. Coldframes can be placed inside or outside a greenhouse. A simple coldframe can be built for a very low cost and can be used effectively to strike cutting or germinate seed (though not as effectively as heated beds).
- Shadehouses - Use for protecting young plants, usually after removal from the propagating area and planting up into the first container. Shadehouses allow for plants to be gradually eased out of their highly protected propagating area to the harsher outside environment.
- Mist systems - These involve a series of mist-producing sprinklers which spray the cuttings or seed at controlled intervals. They serve to prevent drying out and to keep the propagating plants cool in the leaf zone.
- Fogging systems - Fog systems are used as an alternative to the more traditional method of intermittent misting to provide cuttings with a humid environment. The advantage of a fog system is that it still creates the humid environment, which is necessary to prevent the cuttings from drying out, but eliminates the water droplets that sit on the leaves in mist systems. The absence of free water from the leaves results in reduced fungal problems, reduced leaching of leaf nutrients and improved aeration of the propagation media.
- Fluorescent light boxes - Plants of many species propagate well under artificial light. The cool white fluorescent tubes are preferable.

Short wall greenhouse

ENVIRONMENTAL CONTROLS

Greenhouses are used to control the environment in which plants grow. The environment is extremely complex though, and there are many interactions between the various factors. For example, the amount of light (solar radiation) entering the greenhouse might affect the air temperature, or if you close the vents or doors of a greenhouse, you may stop the temperature from dropping, but may be changing the balance of gases in the air. Every time one factor is altered, a number of other factors are also affected.

Greenhouse management involves giving careful consideration to the full implications of every action you take.

The Environment and Plant Growth

The environmental factors that influence the growth of plants inside the greenhouse are:

- Atmospheric temperature – the air.
- Root zone temperature – in the soil or hydroponic media the plants are growing in.
- Water temperature – the water used to irrigate plants.
- Light conditions – shaded, full light, dark.
- Atmospheric gases – plants give off oxygen but take in carbon dioxide during photosynthesis. Plants will take in some oxygen during respiration (converting stored foods such as glucose into energy) and release some carbon-dioxide, but in an enclosed environment the amount of carbon-dioxide in the atmosphere will soon diminish.
- Air movement – mixes gases, and evens out temperatures.
- Atmospheric moisture – humidity.
- Root zone moisture – water levels in the soil or media.

Temperature Control

Greenhouse temperatures can be controlled in several ways:

- The sun will warm the greenhouse during the day. This effect varies according to the time of year, time of day and the weather conditions that day. The way the greenhouse is built and the materials used in construction will also influence the house's ability to catch heat from the sun, and hold that heat.
- Heaters can be used to add to the heat in a house. The heater must have the ability to replace heat at the same rate at which it is being lost to the outside, so that desired temperatures can be maintained.
- Vents and doors can be opened to let cool air into the greenhouse, or closed to stop warm air from escaping.
- Shade cloth can be drawn over the house to reduce the amount of sunlight energy being transmitted into the greenhouse. (Greenhouse paints such as whitewash can be applied in spring for the same effect. The type of paint used is normally one which will last the summer, but wash off with weathering to allow penetration of warming light in winter).
- Coolers (blowers etc) can be used to lower temperature.
- Watering or misting systems can be used to lower temperature.
- Exhaust fans can be used to lower temperature.
- Water storage, or rock beds, under the floor or benches of a glasshouse can act as a buffer to temperature fluctuations.
- Hot beds used to heat root zone areas will also help heat the greenhouse in general.
- Thermal blankets can be drawn across the top of greenhouses at night, usually by means of a small hand-operated winch to trap heat gained during the day.

Heat loss

An important consideration in temperature control is the heat lost through the walls and the roof of the house. Different types of materials (eg. glass, plastic etc) have differing levels of ability to retain heat. Heat is normally measured in BTUs (British Thermal Units). The table below provides some insight into the respective qualities of different materials.

COVERING MATERIAL	HEAT LOSS (BTU/SQ.FT/HR)
Glass (6mm / 1/4 inch)	1.13
Double layer glass	0.65
Fibreglass reinforced plastic	1.0
Acrylic sheet (3 mm thick)	1.0
Polythene film	1.15
Polythene film (double layer)	0.70
Polyester film	1.05

(from *Greenhouse Operation* by Nelson, Prentice Hall)

Heating systems

There are two main types of heating systems:

1. Centralised heating system
   This is normally a boiler or boilers in one location generating steam or hot water which is piped to one or more greenhouse complexes. This is usually the most expensive to install and may be more expensive to operate. There are side benefits though (eg. steam which is generated can be used to sterilise soil, pots etc). This type of system is only appropriate in large nurseries or hydroponic setups.

2. Localised heating systems
   This uses several individual heaters, normally blowing hot air into the greenhouse. Hot air is often distributed through a plastic tube (or sleeve), 30-60 cm diameter which is hung from the roof and has holes cut at calculated intervals for distribution of warm air.

The main types of localised heaters are:

Unit Heaters

These consist of three parts:

1. Fuel is burnt in the firebox to provide heat at the bottom of the unit (the fuel could be gas, oil or something else).
2. Heat rises through a set of thin-walled metal tubes or pipes, which heat up.
3. Behind the heated tubes is a fan which blows cold air through the pipes out the other side into the house.

Convection heaters

These are cheap to purchase and consequently are frequently used by hobbyists and small commercial growers. They differ from unit heaters in that they do not have a built-in heat exchanger. Fuel of almost any type can be combusted in the firebox (eg. wood, coal, gas, oil). Hot fumes then pass out of an exhaust pipe which can be placed between rows of plants, above the heater, or wherever desired. The exhaust pipe should be sufficiently long (or outlets placed far enough away from plants), to ensure dangerously hot air does not come in contact with the plants.

A metal stovepipe or insulated ducting is ideal, however polythene tubing can be used as well. A pot belly stove or something similar could be used as a convection heater.

Note that when fuel is used for heating, it is important that sufficient oxygen is available in the greenhouse and that complete combustion occurs, as a side effect of incomplete combustion is the gas ethylene which can cause major crop damage if it contaminates the greenhouse environment.

Electric heaters

In some areas electricity is cheap. If you happen to have cheap electricity, an electric heater may be considered. These generally consist of a heating element and a fan which blows air across the heating element and into the glasshouse.

Radiant heaters

Low energy, infrared radiant heaters have become popular in the US in recent years. Growers report significant savings on fuel costs.

Solar heaters

There are several different types of solar heaters which can be used or adapted for use in greenhouse heating. The components of a solar heater are:

1. A collector. These are usually panels heated by direct sunlight. The front is transparent to allow light in, the back is black and insulated to stop energy escaping. Light is converted to heat when it is absorbed by the dark surface.
2. A heat store. Water and rocks are two of the most common stores. Water can be passed through the collector and returned to a storage tank of water. Air can pass through the collector and return to the storage tank of rocks.
3. A heat exchanger. Pipes or tubes can pass through the heat store and out through the greenhouse and back to complete the cycle. A heat exchange fluid, or perhaps air can flow through these pipes.

A backup heater may be needed to be used in conjunction with a solar system.

Light Control

Shading

Natural light levels in some greenhouses may at some times of the year become too great for some plants. Excessive sunlight can also cause problems by heating the greenhouse too much. The need to provide shading will depend on:

- Construction - materials Fibreglass, for instance, does not allow as much light into the greenhouse as glass does.
- Location - Greenhouses in warmer climates more frequently need shading.
- Aspect - In the Southern Hemisphere, greenhouses on a north slope running on an east-west line will catch more sun than houses on a south slope running on a north-south line. The opposite applies in the Northern Hemisphere.
- Time of year - Shading becomes more critical in summer than in winter.
- Type of plants - Some plants need more shading than others.

Shading includes using shadecloth attached to the outside of the greenhouse or roll-down blinds. If the blinds are fitted on the outside the temperature inside is reduced, however, usually the ventilators cannot be opened. If the blinds are fitted on the inside the internal temperature is not reduced, but the light intensity is. Blinds can be automated to open and close on preset temperatures.

Another method is using double sheets suspended from the internal roof trusses lengthways. These mechanically controlled systems roll the double layers into very small diameter rolls that minimise the loss of light. The upper layer is a white polyester fabric that reduces light by 45% while the lower polyethylene level permits 90% of the light to pass to the crop.

A less commonly used method is to apply a shading paint called Lightening Crystals, which can be sprayed on the roof. However it is not removable, limiting its practical use in many situations.

Paint-based shading compounds

Paint-based preparations are ideal for semi-permanent shading requirements. They are applied with a brush, roller or spray gun to various densities, according to shading requirements of the species grown. There a number of preparations available that can be applied in spring when light intensifies, directly to the outside of the greenhouse. Light-coloured acrylic-based paints have a long-lasting effect.

A Belgian product, Parasoline, now available in a number of countries, overcomes the problem of too much shading at times of low light. This product has the ability to change from a white light reflecting layer during sunny conditions, to translucent in rainy conditions, allowing light penetration.

Supplementary Lighting

Greenhouse structures frequently use lighting to assist growth by supplementing natural light. Plants will respond to the artificial lights as all lamps radiate different qualities of the light spectrum.

Lamps used in greenhouses are normally one of the following:

1. Incandescent - (tungsten filament) These are generally not ideal in nurseries. Among other things the quality of light is poor and they create excessive heat. They have a high proportion of red light and this can facilitate fast stalk growth and blooms at the expense of longevity.

2. Fluorescent - (eg. Gro-Lux fluorescent lamps) Fluorescent lamps have been useful in propagation areas and with young plants, but are not suitable for plants in the latter stages of production. They increase flowering for a longer duration.

3. High intensity discharge - (eg. high pressure mercury or metal halide) These are the best for plants in the latter stages of production, prior to selling and to promote stem thickness.

Humidity

Humidity can be increased in the growing environment in the following ways:

- Using equipment such as humidifiers or fogging machines.
- Periodically spraying a fine mist for a short period through a fine sprinkler head.
- Using moist mulch around the plants (eg. woodshavings are sometimes laid on the greenhouse floor and kept wet to raise humidity.

Ventilation Systems

Use of vents and fans to control both temperature and the balance of gases in the greenhouse environment is a very important aspect of the management of any greenhouse. Ventilation is required to remove used air and maintain air circulation. This constant circulation reduces the likelihood of a fungal disease outbreak.

Cooling equipment ranges from manually operated vents and shadecloth coverings in simple setups, to fully-automated cooling fans and ventilators in large commercial ventures. In very large houses, the use of forced air fans becomes more necessary. Cool air is introduced by evaporative cooling, where fresh air is cooled and pumped into the greenhouse and the hot air is sucked to one end and dispelled. Air passed through fans can be heated or cooled for additional temperature control. By connecting fans to an electronic thermostat it is possible to have them switch on and off automatically as and when ventilation is needed for temperature control.

Placement of the pad and fans of the evaporative cooling system is important. The most versatile placement of the pad is inside the greenhouse wall, allowing ventilators in that wall to open and close to adjust to weather conditions. Exhaust fans should be at least 5 m apart from the pad, to prevent warm, moist air moving towards an intake pad. When greenhouse walls are less than 4.6 m apart, fans in adjacent walls should be alternated so they do not expel air toward each other.

Plants inside a greenhouse should be kept as far away as possible from vents or fan outlets (temperature variations can be more extreme in these positions).

Greenhouses require a vent area that is at least 30% of the floor space area to allow for sufficient air exchanges per hour, temperature control and gas exchange. Greenhouses in tropical climates are advised to have greater than 30% as vent area.

Shade cloth curtain (retractable) inside greenhouse

COMPUTERISED ENVIRONMENTAL CONTROL

Computers are capable of delivering a 15 to 25% saving in costs, and reduce labour considerably in the greenhouse. Computer-controlled equipment that manages the greenhouse environment is widely available. Such equipment can control temperature, humidity, light intensity, application of black cloth shade, light reduction as needed, ventilation fans and irrigation.

Computer-controlled environments can control the temperature to within one-tenth of a degree where manual control is at best within 2-3 Degrees. They also do the job gradually, which puts less load on the equipment as compared to the abrupt changes resulting from manual operation. Computer controls work 24 hours a day, 7 days a week. When used correctly, they continuously deliver the most cost-efficient control of heating/ventilating systems.

Intelligent Environmental Controllers

The most recent types of computer-controlled equipment are known as 'intelligent environmental controllers'. These systems are capable of sensing, adjusting and recording all aspects of the greenhouse environment, including temperature, light intensity, carbon dioxide concentrations and humidity.

Sensors are strategically placed within the greenhouse and linked to external computers which are programmed to activate an optimal balance of growing conditions. The measurements and adjustments are made to maintain growth at the fullest potential, without unnecessary expenditure of energy. The adjustments are recorded so that the grower can ensure growing conditions are maintained at optimum levels. Furthermore, the new computer control systems are manually programmed, which allows the grower to alter growing parameters to accommodate a new crop or incorporate new information.

It is possible for computers to control the flow of nutrients to large hydroponic systems in a greenhouse. This means that settings can be very specific and controlled without the need for regular human intervention. Obviously such systems require a large capital outlay and are suitable only for large commercial ventures.

PEST AND DISEASE CONTROL

Pests and diseases can be more of a problem in a greenhouse than out in the field. On the one hand, the greenhouse is contained, which means it can be protected from infection (providing you practice cleanliness). Unfortunately, though, once you do get a pest or disease into a greenhouse, it tends to spread throughout the whole house very quickly (partly because the plants are growing so close together, partly because the warmth and humidity of the greenhouse tend to provide ideal conditions for pest and disease problems).

Fungal problems in particular are of great concern in the greenhouse. Proper attention to environmental factors such as temperature and humidity go a long way toward preventing fungal problems. Regular checks and intervention will reduce the likelihood of fungal outbreaks spreading in the greenhouse.

greenhouse

CHAPTER 11 : PLANT CULTURE IN HYDROPONICS

This chapter deals with some of the specific horticultural techniques used to maximise cropping in hydroponics.

PLANT SUPPORT

Plants grown in hydroponics tend to be more prone to falling over than plants grown in soil; and thus frequently need some type of trellis support. Water culture methods such as NFT and lightweight materials such as perlite, vermiculite and rock wool do not provide firm anchorage of roots in the way that soil does.

- Tall growing plants in particular need support.
- Stronger supports are needed if plants are exposed to wind.
- A greater bulk of plant will need a stronger trellis.

There are two types of trellis systems:

1. *Horizontal trellis*

   Here a mesh of wire, nylon or some other material is supported above the plants in one or two layers (depending on the height of the plants and the amount of support needed).

   Carnations, capsicums, and other small bushy plants require this type of trellis.

2. *Vertical trellis*

   This may consist of a similar mesh material stretched along a row, or alternatively, single wires stretched along a row with support posts at each end. Vertical trellis can also be hung from the ceiling in a greenhouse.

- Tomatoes can be grown on wires tensioned and spaced at 50 cm intervals. The stems are tied to the wires as they grow.
- Cucumbers require greater support and are either grown on a vertical mesh, or on wires at 15 to 20 cm spacing. The wires should be tied together every 20 to 30 cm to form a mesh and give additional support.
- In large systems wires need to be connected to turnbuckles so they can be tensioned if they loosen.

PRUNING

Plants are pruned for one of the following reasons:

1. *To remove dead or diseased vegetation*

   This is done so that disease does not spread. Any dead or diseased stems, leaves, fruit or flowers should be cut cleanly from plants and disposed of as soon as it is noticed, irrespective of the crop.

2. *To rejuvenate a plant*

   Young lush growth is always healthier than tired old wood. A rose for instance can have its life extended and health improved, if old wood is continually removed over a period of years, and replaced by younger wood.

3. *To control the direction or shape of growth*

   A plant can be made bushier by removing the terminal bud of a shoot or stem. When the tip is cut or pinched out, side shoots are forced to develop so that several shoots occur where before there was only one. If you want a taller, less bushy plant, side shoots are removed so that there are fewer growing points (e.g. this is done with tomatoes until they establish and begin flowering).

4. *To control the type of growth*

   Some plants produce flowers and fruit on growth which is in its first year. Other plants produce flower buds only on older wood (e.g. two-year-old wood). By knowing the type of wood that flowers occur on, it is possible to prune in order to maximise the fruit or flower crop. By removing all flower buds, it may be possible to redirect a plan's energies into vegetative growth.

Pruning Examples

Raspberries

Raspberries produce fruit on two-year-old wood. These should be pruned each winter as follows:

- Remove wood which produced fruit last season (because this will be 3 years old next season and won't fruit much at all then).
- Leave the strongest growth of one-year-old wood (because those will be 2 years old and will produce fruit next season).
- Leave the strongest half of the new growth which emerged over the past season (i.e. one-year-old wood), because those growths will produce fruit the season after next.

Chrysanthemums

Chrysanthemums produce flowers on the tips of young growth. The more tips a bush has, the greater the number of flowers it will have, but the smaller each flower will be.

- If you require a large quantity of flowers, you will remove the terminal bud when you plant a young plant, and periodically pinch out the growing points in the developing stages of the plant. You must cease removing the growing points when flowers start to develop though, or you will be removing flower buds.
- If you require fewer flowers, but larger and of better qualify, you should cease pinching our terminal buds much earlier.

POLLINATION

Some plants can have problems with pollination, which result in a reduced number of fruit. Corn, strawberries, tomatoes and cucumbers may be affected in this way, particularly if grown in a greenhouse which has reduced air movement and limited access to pollinating insects. The following methods may be used to help pollination in these and other problem situations:

- Fans to increase air movement
- Vibrating the flowers by tapping them with a stick of shaking them with your hand (not too hard though or you will damage the plants).
- Releasing bees into the greenhouse.
- Moving pollen physically from plant to plant with cotton wool or some similar material.
- Reducing humidity (which can cause pollen to stick on the plant it comes from and not move to where it is needed).

If you are planning to do any of these things, they must be done at the appropriate time, when the plant is receptive (e.g. tomato pollination should be done in later morning, under sunny conditions when the petals of the flowers are curling back).

CARBON DIOXIDE ENRICHMENT

Plants need carbon dioxide in the same way that humans need oxygen. Without a good supply of carbon dioxide growth will slow.

In some crops and in some localities, yields can be significantly increased by increasing the level of carbon dioxide in the growing environment. This is of course most suited to a sealed greenhouse. In an enclosed environment such as a greenhouse, there is a real danger of plants becoming starved for carbon dioxide. If vents to the outside are closed, the plants will in their normal course of growth gradually deplete carbon dioxide until they reach a level where growth is slowed.

The optimum level for most crops will be around 1000 to 1400 ppm (although natural levels are only around 300ppm). Nutrition and water demand may increase when carbon dioxide is used.

Methods of supplying carbon dioxide are:

- At the same time heating a greenhouse: burn a hydrocarbon fuel such as kerosene or propane.
- Place containers of dry ice in the greenhouse.
- Release gas from pressurised cylinders.

Carbon dioxide enrichment can benefit the crops below as follows:

- Commercial tomato growers in northern parts of the USA claim crop increases of 20 to 30%.
- Lettuce and cucumber yields increase up to 30% in cool climates.
- Carnations crop faster, have stronger stems and will give production increases of up to 30%.
- Roses under 1000 ppm carbon dioxide levels over winter in cool climates have increased production, improved quality and shorter cropping times.
- Chrysanthemums have stronger and longer stems and crop faster.

young chrysanthemums

TRANSPLANTING

Whenever you transplant a seedling into hydroponics there will be some "shock" effect which is detrimental to the plant and will result in either:

- Some dieback on the root system – some of the root hairs and perhaps root tips may die; or
- A break in the growth – growth will slow or cease for a period.

This shock effect will normally be unnoticeable with hardy and easy to grow plant varieties, but can be significant in some situations.

Transplant shock can be minimised by following these rules:

- Don't disturb roots any more than is necessary.
- Use young plants growing in hydroponic media such as Growool where possible, so that the propagating medium can be retained and most of the roots do not have to be exposed.
- Roots should be exposed to the air for the absolute minimum amount of time
- Don't transplant in hot, windy or dry conditions.
- If planting into NFT, have the system running before you start transplanting.
- If planting into aggregate, apply nutrient solution before transplanting.
- If planting onto rockwool slabs, soak the slabs with nutrient solution before transplanting.
- If you damage or prune the roots of a transplant, cut a corresponding amount of the top back before transplanting.
- Plants which are more susceptible to transplant shock can be sprayed with a mist of water (not nutrient solution!) just before transplanting.
- Irrigate plants immediately after transplanting.

MANAGING PLANT HEALTH

Diagnosis of Problems

Problems fall into three possible categories:

1. *Nutritional* – either too little or too much of one or several particular nutrients is available.
2. *Environmental* – The environmental conditions are not suitable.
3. *Pathological* – One or more organisms are interfering with the health of the plant. Such organisms are called "pathogens".

It requires a great deal of knowledge and expertise to be able to diagnose plant troubles. Do not expect to develop such ability quickly. The first and perhaps most important skill to develop is an ability to inspect a plant and look for the tell-tale symptoms which can provide an indication of what might be wrong.

The table at the top of the next page provides a systematic approach to inspecting plants which you suspect (or know) might be unhealthy. You should look at each of the 'items' one at a time, following the guide given by the 'method of inspection' column.

Tell-tale Symptoms

1. *Wilting*

- Insufficient water in the soil.
- Leaves drying out faster than the water can be taken up (too hot).
- Something stopping water going up the stem (e.g. borer, disease, etc in lower part of plant). Take a close look!

2. *Yellow Leaves*

If older leaves:

- Lack of nitrogen (feed with a nitrogen fertiliser)
- Lack of nitrogen caused by wet soil – wet soil stops nitrogen being taken into the plant (improve drainage or reduce watering).
- Chemical damage.
- Soil very dry.

If younger leaves:

- Iron deficiency.
- Other nutrient deficiency.
- Chemical damage.

3. *Distribution of damage*

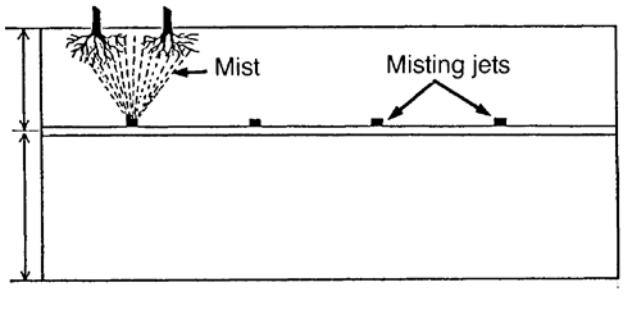
Look to see if the damage is evenly distributed over the plant. Is there a pattern:

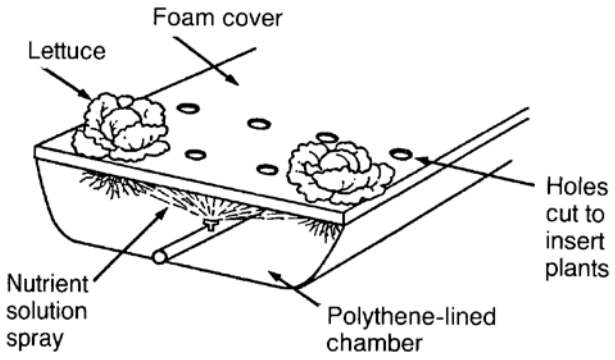
- On one side only?
- On the top only?
- One the most exposed parts?

4. *Duration of damage*

Look to see whether the damage has only just happened or it has happened in the past.

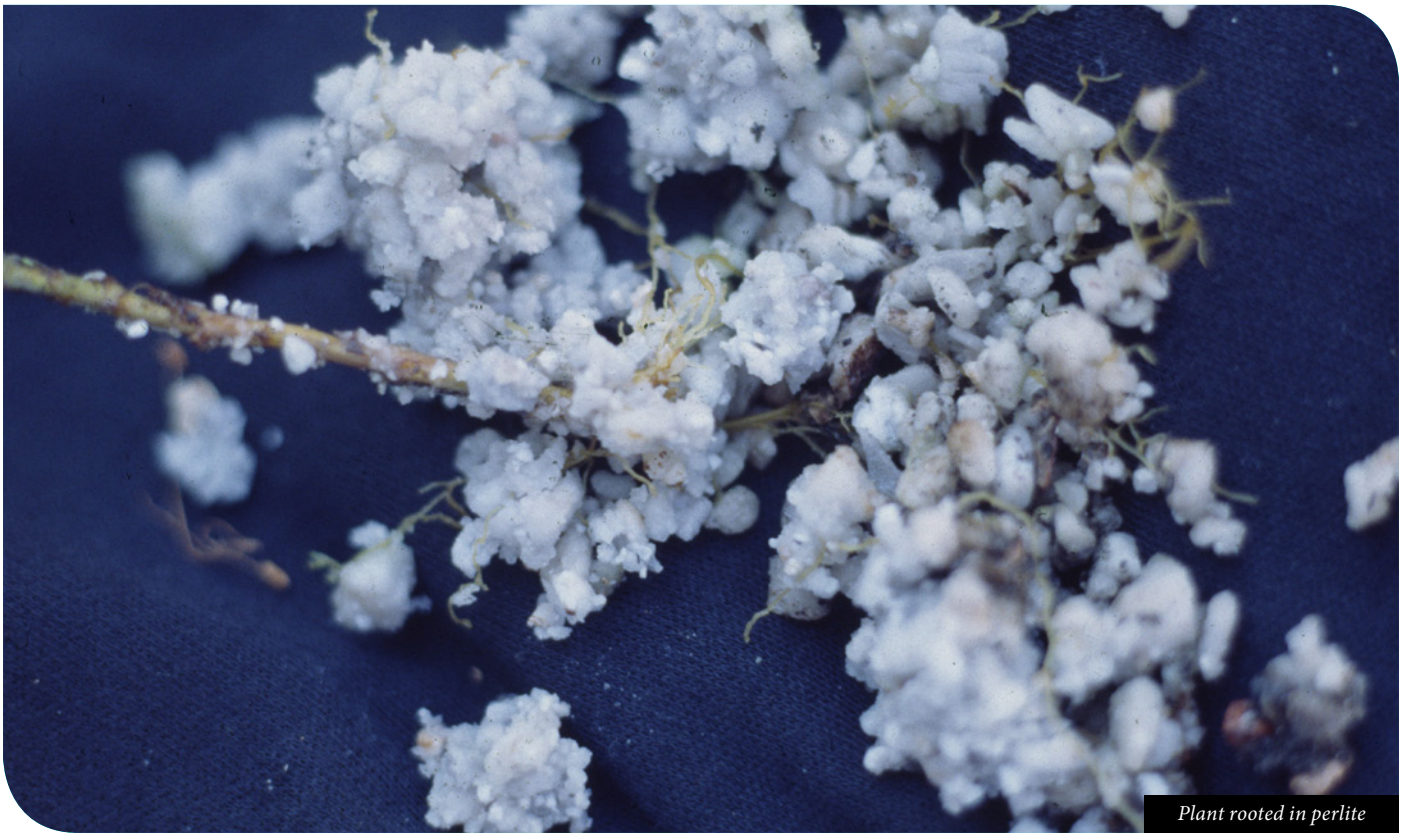
- The appearance of the growing tips tells you the current condition.
- Young shoots indicate a healthy plant overcoming past problems.
- Excessive side shoots lower down indicate disruption of hormone flow in the plant.





How Aeroponics Works

ITEM	METHOD OF INSPECTION	WHAT TO LOOK FOR
Leaves	View old and young leaves – both above and underneath	Burning; discolouration; holes; leaf drop; insects – live or dead.
Stems	View top to bottom, push foliage out of the way. Binoculars for tall plants	Stem rot; spots or other markings; suckering; side shoots; thin or thin stems.
Growth Habit	Stand back and view, look at where strong growth is and direction of buds	Is it balanced? Appropriateness for type of plant (bushy for shrub, strong terminal growth for tree, etc); growth rate.
Soil	Feel surface of soil, push finger 2-4 cm below surface. Remove plant from pot	Moisture/dryness; hardness, root density; burrows; wet/dry spots.
Roots	View holes at bottom of pot. Remove plant from container. View surface of soil	Root tip burn; rotting; distribution of roots – even? Discolouration; growing tips; visible presence of insects, nematodes, etc.



Plant rooted in perlite

Plant Health Report Form

The following form can be used to make a systematic study of a problem when it arises. This form is not comprehensive and more alternatives could be listed under problems and recommendations. Unless you are a pest and disease expert, it can be easy to overlook something important if you do not take a systematic approach such as this.

History.....
Report By.....
Date.....
Location .....
Plant name.....
Common Name.....

Condition of Plant (tick)
( ) Very healthy
( ) Healthy
( ) Medium Health
( ) Sick
( ) Very Sick
( ) Almost dead
( ) Dead

Maturity (tick)
( ) Young
( ) Mature
( ) Old

Estimated height.....
Estimated width.....
Estimated lifespan.....

PROBLEM	Extent of Problem *(Existing/Developing/Extensive/Slight)*
Chewing insects	
Dead parts	
Sucking insects	
Wood rot	
Fungal disease	
Water stress	
Cold	
Heat	

RECOMMENDATION	High Priority/Medium Priority/Low Priority
Remove Plant	
Spray Chemical	
Pruning	
Change Cultural Practice	

Actions to be taken.....
Equipment Needed.....
Time required.....

PESTS

The term plant pests can include a wide range of organisms including:

- Insects which feed on plants or which transmit other problems such as fungal and viral diseases from plant to plant.
- Animals which cause physical damage by digging around plants, knocking plants or eating plants (e.g. goats, birds and dogs).
- Animals causing burn to plant tissue by urinating on them (e.g. dogs).
- Man causing physical harm to plants by compacting soil through over-use, knocking and damaging plant tissue, transmitting diseases to the vicinity of 'clean' plants, and through other forms of mismanagement.
- Snails, slugs, nematodes, yabbies, wood lice, mites and other small animals feeding on plants, transmitting diseases, etc.

Feeding habits

The following may assist in quick identification of insects and other pets causing damage to a plant. They are grouped below according to the type of pant damage which they cause. The list is not exhaustive, but it should cover most common types you will encounter.

- Insects and other pests which chew above the ground: armyworm, bees, bugs, beetles, caterpillars, crickets, cutworm, earwig, grasshopper, leafminers, leafrollers, leaf skeletonisers, sawflies, slugs, snails, springtails and weevils.
- Insects and other pests which feed below the ground: root aphis, root nematodes, root borer, rootworm, root weevil, woolly aphis, wireworm, beetle larvae
- Borers: codling moth, bark beetle, corn, earworm, white pine weevil, melon worm, longicorn weevil, European apple sawfly, etc.

Common Pests and Their Control in Hydroponic Culture

Aphis

These are small insects which cluster in large numbers on tender growth (typically on tips of growing shoots, flower buds and occasionally roots). They can usually be controlled with an organic pyrethrum spray. Malathion will give good control, but should not be used on food crops close to harvest.

Birds

Birds will attach and eat fruits from many plants including tomatoes and strawberries. Greenhouse crops are protected by the greenhouse cover. Bird netting is an effective control, but it can be very expensive. Regular picking of near ripe fruit will minimise the problem.

Cabbage White Butterfly

This is the caterpillar of a white butterfly. See caterpillar (below).

Caterpillars

Caterpillars are chewing grubs which eat foliage and sometimes other plant parts. Control safely with a spray of Dipel™ (this is a bacteria, *Bacillus thuringiensis,* which attacks and kills caterpillars, but has no effect on any other type of insect or animal). Malathion or Carbaryl will give good control, but shouldn't be used on food crops close to harvest.

Crickets

Crickets are not a frequent problem, but can occasionally occur in large numbers and eat anything in sight. Malathion is an effective control.

Grubs

Grubs are the larvae of many different types of insects which burrow inside fruits, stems or other plant parts. As they are on the inside of the plant, most insecticides will not kill them. These can only be controlled by either removing and burning the infected parts, or treating with a systemic insecticide such as rogor (Dimethoate).

Leafhoppers

These are tiny insects feeding on the lower surface of leaves causing major mottling or flecks on foliage. These can be treated by spraying with Carbaryl or Malathion.

Leafminers

Leafminers are insects whose grubs burrow tunnels through the leaves. Tunnels appear white or clear at first. These can be treated by spraying with Diazinon or Malathion.

Mealy Bug

This is a small fluffy scale-like insect (with a cotton wool-like covering). It is a sucking insect related to scale and aphis. It occurs in moist organic material (such as wood or peat moss), and occurs on protected underside of leaves in humid or moist, warm conditions. Mealy bug can be controlled with Malathion. Regular sprays of pyrethrum give a lower toxicity control, although it is not as thorough.

Mites

These are tiny spiders, virtually impossible to see with the naked eye, though in large numbers they can cause a haze of red colour. Mites can attack foliage, fruit and other plant parts on many different crop plants. They occur in hot, moist conditions. Mites can be controlled safely by releasing parasitic mites which feed on the plant pests. To control, spray with malathion, dimethoate, or difocol.

Scale

Scale are shield-like insects which attach themselves to the surface of stems, fruits and leaves. Scale can be controlled by smothering with a spray of white oil.

Thrip

Small flying insects which suck plant sap causing flecking on flowers or foliage of many different types of plants. For control, spray with pyrethrum, rogor or malathion.

Whitefly

These are small white, flying insects which move in great numbers when disturbed. Whitefly can be controlled with malathion.

PLANT DISEASES IN HYDROPONIC CULTURE

Plant disease is generally distinguished from insect and other pest problems. Plant pests actually eat the plant, or break the plant by standing on it (as does the human pest). Plant disease is far more subtle, disturbing the microscopic physiological processes within the plant.

When a plant is diseased, it may be affected by one, two or more different problems. It is often difficult to identify what is wrong with a plant clearly, because the problem is in fact a combination of problems.

A possible scenario is outlined in the example below:

- The plant is weakened by poor nutrition.
- Excessively wet conditions create an environment conducive to the growth of an infectious fungus.
- The plant, weakened by poor nutrition, is infected by the fungal diseases that develop in wet conditions.
- The roots begin to rot through fungal attack.
- Because the roots are damaged, the plant does not take in water and nutrients as well as it would normally.
- The leaves of the plant are infected by a second disease because of the above situation, which has made the plant weak and less able to repel infection.
- Disease organisms reproduce spreading infection much wider

diseased strawberry

Disease organisms usually fall into one of the following groups:

Viruses

Viruses are very small microscopic particles composed of nucleic acid and protein. They exhibit many, but not all, characteristics of living organisms, and are therefore sometimes called a life form. Viruses can mutate. They cause many serious diseases, frequently causing variegation or mottling of leaf colour. Some viruses are considered beneficial because of the variations they provide in leaf colour. Whether considered beneficial or not, viruses cause a general weakening of plants they infect, making the plant more susceptible to other problems, and frequently stunting growth to some degree.

Bacteria

These are single-celled organisms, some of the smallest living things. They enter plants through stomata or wounds. (They cannot break directly through cell walls or the 'surface' of a plant). Bacteria can cause rots, blights, spots, galls, scabs and other symptoms. (N.B. Fungi can also cause many of these.)

Fungi

Fungi are chlorophyll-less members of the Thalophyte plants. They are either parasites (living on live tissue) or saprophytes (living on dead tissue). Over 15 000 species are known, and many are responsible for major plant diseases. Fungi are thread-like organisms which grow amongst the tissue from which they derive their nutrition. The individual threads are known as mycelium. To reproduce, fungi grow fruiting bodies from a mass of mycelium, and spores are produced in these fruiting bodies.

Nematodes

These are microscopic worms which feed in the intercellular spaces, causing breakdown of cell walls. They generally enter plants through the roots, through wounds or stomata (different nematodes have different standard methods of entry). Nematodes are much less of a problem in hydroponics than in soil.

Common Terms Used to Describe Diseases

- Rot: Decomposition or decay of dead tissue.
- Spot: Well defined grey or brown tissues surrounded by purplish margins (or margins of some other dark colour).
- Shot hole: Dead tissue in a spot cracks and falls, leaving a hole in the leaf.
- Blotch: Fungal growth appearing on the surface of a dead spot.
- Blight: Quick death of complete parts of a plant. The disease pathogen develops very quickly, e.g. leaves die and fall.
- Wilting: Drooping of leaves and/or stems.

- Scorch: Similar to blight but leaf veins are not affected. Leaf tissue dies between the veins, or along the margins.
- Scald: Whitening of surface (or near surface) cell layer on fruit or leaves.
- Blast: Unopened buds or flowers die suddenly.
- Die back: Death of growing tips, moving down through the plant (i.e. the terminal buds dies, followed by death of the stems and lower parts of the plant). Die back can occur to just part of the plant or, in severe cases, can continue moving through the plant to the roots.
- Damping off: Sudden wilting and falling over of young plants due to tissue being attacked by fungal disease near the soil line.
- Mummification: Diseased fruit dries up, becoming wrinkled and hardening as it shrinks.
- Canker: Death of a restricted area of woody tissue, usually a callus of healthy growth forms around the edge of the canker.
- Bleeding: A substance is exuded from a diseased part of the wood. Only refers to exudation which is not resinous or gummy.
- Gummosis: Bleeding where the exudation is resinous or gummy. Gummosis on conifers is called *resinosis*.
- Firing: Leaves suddenly dry, collapse and die.
- Rosettin: Spaces between leaves on step do not develop: buds and leaves become squashed together within a short section of stem.
- Mosaic: Mottling of yellow and green on leaf surface.
- Dwarfing: Plants do not grow to full size.
- Fasciation: Round plant parts such as stems become distorted, broadened and flattened.

PHYSIOLOGICAL PROBLEMS

There are a number of environmental factors which can damage a crop if not properly controlled. Frost or sun may burn fruits or foliage, fruit can crack and leaves can discolour. Some of the more common problems are detailed below.

Cracking

Lack of water or excess water can cause the skin of various crops to split. Freshly harvested carrots sometimes split. Tomatoes that are suffering from lack of water and exposed to high temperatures may split.

Blossom end rot

A common problem with tomatoes is where the bottom of the tomato turns brown or black and leathery in appearance. This typically occurs where there a low supply of calcium combined with irregular growth, causing stress in the plant. Irregular and variable water supply and variable temperature conditions are also associated with this problem.

Crooking

This is where fruit becomes distorted (eg. when cucumbers become excessively curved). Crooking has been attributed to poor control of temperature, moisture or nutrition.

COMMON DISEASES AND THEIR CONTROL IN HYDROPONICS

Alternaria

This blight commonly affects leaves, sometimes stems. Symptoms are usually spots, often developing concentric rings as they enlarge. There are many types of alternaria. Most are controlled with Zineb. A copper spray will control some.

Anthracnose

There are two different groups of anthracnose diseases, distinguishable by their symptoms:

1. Symptoms are dead spots.
2. Symptoms are improper development of some part of the plant (e.g. a raised border around a depressed central area of undeveloped tissue.

Anthracnose can be controlled by various fungicides. Some types are controlled by copper sprays, others by Zineb and other chemicals.

Botrytis

A grey fluffy mouldy growth occurring on stems, leaves, flowers and leaves, botrytis occurs in wet, humid conditions. Affected parts should be removed and burned immediately.

Preventative measures include increasing airflow and reducing humidity. Thiram and dichlofluanid fungicides can be used to control infections.

Downy mildew

The upper leaf of a plant with this disease shows yellowing or dull patches with a greying mould growing underneath. It occurs under most conditions, and is controlled with Zineb.

Fusarium

Symptoms can include foliage yellowing, stunted growth, wilt and leaves dropping. Hygiene will usually control fusarium.

Phytophthora

There are several forms of *Phytophthora* ranging from disease that the stem of young seedlings to others that impair the uptake of nutrients in very large plants. Symptoms are frequently dramatic and can cause sudden death of the plant.

Remove infected parts and sterilise infected areas. Fongarid will effectively control some types of phytophthora and slow the spread of others.

Powdery mildew

This disease occurs in warm, moist, humid conditions The main symptom is a white powdery growth on leaf surfaces. Sulphur sprays or dust will usually give control.

Rhizoctinia

Symptoms are brown or black dead spots or rot, normally on leaves

or stems. This disease can be controlled with terraclor.

Scab

Patches of discoloration develop into spongy, blister-like scabs which can affect leaves, stems or underground parts. Remove or burn infected parts. Spray with dithane (Maneb).

Smut

Symptoms are black spots with cracks developing in the spots to reveal a sooty black powder. Control with Maneb.

powdery mildew

Verticillium wilt

The disease infects a variety of crop plants. Symptoms may be as mild as slight paleness in foliage to drooping of leaves, stunted growth, browning between the veins of a leaf, and death. Symptoms can be slow or reasonably fast to develop. Infected plants should be removed and burnt, and infected areas should be sterilised before replanting.

Virus

Symptoms can be any type of abnormal growth, such as discolouration of foliage, twisted or stunted growth etc. Once a plant has a viral disease, it is virtually impossible to eliminate it from that plant. Prevent spread by controlling sucking insects (in particular aphis). Some plants (e.g. strawberry) deteriorate with the virus over a period of years. Control in such instances involves replacing plants every few years with verified virus-free stock.

INTEGRATED PEST MANAGEMENT (IPM)

The main ways of controlling pests and diseases are as follows:

1. Sanitation

2. Resistance plant varieties

3. Biological control

4. Soil drenches/dips

5. Chemical controls

Increasingly hydroponic growers are using a variety of controls – chemical, cultural and biological – to minimise crop damage. While chemicals have proven to be effective in controlling certain pests in the past, their sole use is no longer advocated due to concerns over chemical residues in food, environmental contamination, and the increasing resistance of many insects to chemical pesticides.

Integrated Pest Management (IPM) avoids overuse of chemicals by creating a growing environment where there is a balance between sustainable environmental practices and profitable crop production.

The successful implementation of an IPM program relies on monitoring crop and pest populations. Sticky traps are often used for this purpose. Staff must be trained to distinguish and identify beneficial insects from pests.

IPM practices include:

- Installing micro-screens on air intake vents in greenhouses.
- Using clean seeds.
- Eliminating vegetation around the greenhouse.
- Cleaning hands, etc., prior to handling material.
- Monitoring pest levels and acting before they become a problem.

Beneficial insects available to greenhouse producers includes predatory mites, beetles, wasps and nematodes.

FORMS OF APPLIED INSECT CONTROL

The following steps should be followed:

1. Detect the problem.
2. Identify the insect involved.
3. Find out about the biology of the insect.
4. Consider how important it is to control the insect.
5. Consider the alternative control methods.
6. Select the most appropriate method and carry out what action is necessary.
7. Evaluate.

Mechanical Control

This involves using specific physical equipment or techniques such as insect screens, plant enclosures, metal shields (on building foundations), sticky banks in the path of insects etc. The key to mechanical control is to use the appropriate method at the appropriate time. *Timing is very important!*

Some specific examples of mechanical control include:

- Banking the legs of a bench with a sticky layer will prevent and trap insects crawling up onto the bench (e.g. ants)
- Draping young plants with a covering of cheesecloth will discourage cicadas
- Wrapping the trunk of a transplanted plant will prevent some types of borer attack
- Paper or plastic collars around a plant will discourage movement of cutworms
- Tree-wound paints can provide a barrier of wood borers and some types of ants.

In some situations, irrigating an area heavily will kill off insect populations (perhaps flood irrigation a system if the medium has become heavily infested).

Raising or lowering temperatures can also be used to kill insects (e.g. in seed or grain, temperatures of over 140 degrees F may kill insects without damaging the seed). Usually, low temperatures will slow or stop insect activity, but without killing them as do high temperatures.

Certain types of radiation (e.g. gamma rays or microwaves) may be used to control some types of insects (e.g. gamma rays can make some insects sterile).

Cultural Control

Cultural control is a long term approach to managing insect populations. It is based on the concept that the best methods of growing plants will stop insect populations from developing in large numbers.

Cleanliness is an important part of cultural control. This relies on removing infected plants or parts of plants as soon as they are found (e.g. infected fruit should be picked and burnt as soon as it is noticed).

Crop rotation is another important cultural practice, even in hydroponics. The basis of crop rotations is to avoid growing consecutive crops in the same place if they share a pest or disease problem. By following a crop of lettuce, for instance, with a crop of tomatoes, the pests which are a problem on lettuce (which may remain on your property after harvest) have nothing to grow on while the tomatoes grow. Hence the lettuce pests die out.

Biological Control

This involves manipulating biological factors to control insect populations. This includes:

- Using resistant varieties of plants bred or selected because of their ability to withstand pests.
- Using predators which attach or cause harm to the insects (e.g. Dipel is a commercially available spray of bacteria which attacks and kills caterpillars. Some ladybirds attack and kill some scale).
- Manipulating the environment (i.e. destroying environments close to your crop where the pest or disease might breed, planting companion plants amongst your crop etc) with the aim of encouraging and discouraging certain insect species.

Legislation

Governments pass laws to restrict the movement of material which tends to carry pests. Quarantine regulations provide for material to be kept in a separate area for a time and be inspected for pests before being released into the community. Other regulations can ban the import of certain materials or the entry of unauthorised persons into certain areas.

SUMMARY OF INSECTICIDES

The most commonly used insecticides fall into one of the following groups

- Inorganic insecticides e.g. arsenic trioxide, boracic acid. These are generally persistent (they remain as a poison for many years, often hundreds of years). They vary a great deal in their toxicity to mammals. Some are very poisonous, others are not.
- Botanical insecticides, e.g. natural pyrethrins. Extracted from certain types of daisy plants (genus: Pyrethrum). These chemicals are generally not very toxic to mammals, and are not persistent (i.e. they break down to harmless compounds within a very short period of time).
- Organochlorine insecticides, e.g. aldrin, chlordane, dieldrin, heptachlor. Mammalian toxicities range form medium to very highly toxic, and the persistence is generally very long. These chemicals can remain active for hundreds of years and are mostly illegal now.
- Organophosphate insecticides, e.g. chlorpyriphos, diazinon, dichlorvos, fenitrothion, fenthion, malathion (i.e. maldison), temephos, trichlorphon. Most are short to medium term in their persistence (lasting up to a couple of months). Toxicities range from moderate to very high.
- Carbamate insecticides, e.g. bendiocarb, carbaryl, methomyl, propoxur. Persistence is short to medium term and toxicities are mainly moderate.

- Synthetic pyrethroids, e.g. permethrin, bioresmethrin, tetramethrin. Mammalian toxicities are generally low but persistence is some can be several months (but not years).
- Characteristics of Pesticides

Consider the following before deciding on using a chemical. Your judgement of what to use should balance all of these factors with safety to yourself, your staff, your customers and the environment. The people from whom you buy chemicals should be able to show you documentation on these details.

Toxicity

This is a measure of the pesticide's capacity to poison. This will, of course, vary from one organism to another – it may be poisonous to one type of insect, but not to another. Toxicity to insects is not always directly related to toxicity to people, domestic animals or wildlife.

Spectrum of activity

This is the range of organisms which it affects. Insecticides such as pyrethrins or dichlorvos are broad spectrum (i.e. they kill a wide range of pests). Chemicals which kill only a small range of insects are called 'narrow spectrum'.

LD50

LD50 is a measure of the toxicity to mammals. It is a measure of milligrams of poison per kilogram of body weight required to kill 50% of test animals. It is generally tested on mice or rats to obtain the LD50 reading. Dermal LD50 is the result obtained by subjecting animals to a dose of the chemical through the skin. Oral LD50 is the result obtained by subjecting the animals to a dose of the chemical through the mouth.

Persistence

Most pesticides will change form gradually after application. The effect of the chemical on organisms it contacts will therefore gradually be reduced. Persistence is a measure of how quickly or slowly the effectiveness of the chemical declines. Persistence is rated in terms of 'half life'. Half life is the length of time from application till the time when the chemical has half the effect it did when it was first applied. Dieldrin, for instance, has a half life of over 100 years, making it very persistent. Malathion has a half life measured in weeks. Some chemicals have a half life measured in hours.

Volatility

This is how easily the chemical becomes a gas. Volatile poisons are more dangerous to work with (e.g. dichlorvos), because they can readily be inhaled.

Repellency

This is a chemical's ability to repel insects from the place where it is applied. Pyrethrins, for instance, repel insects such as mosquitoes and flies.

Flushing action

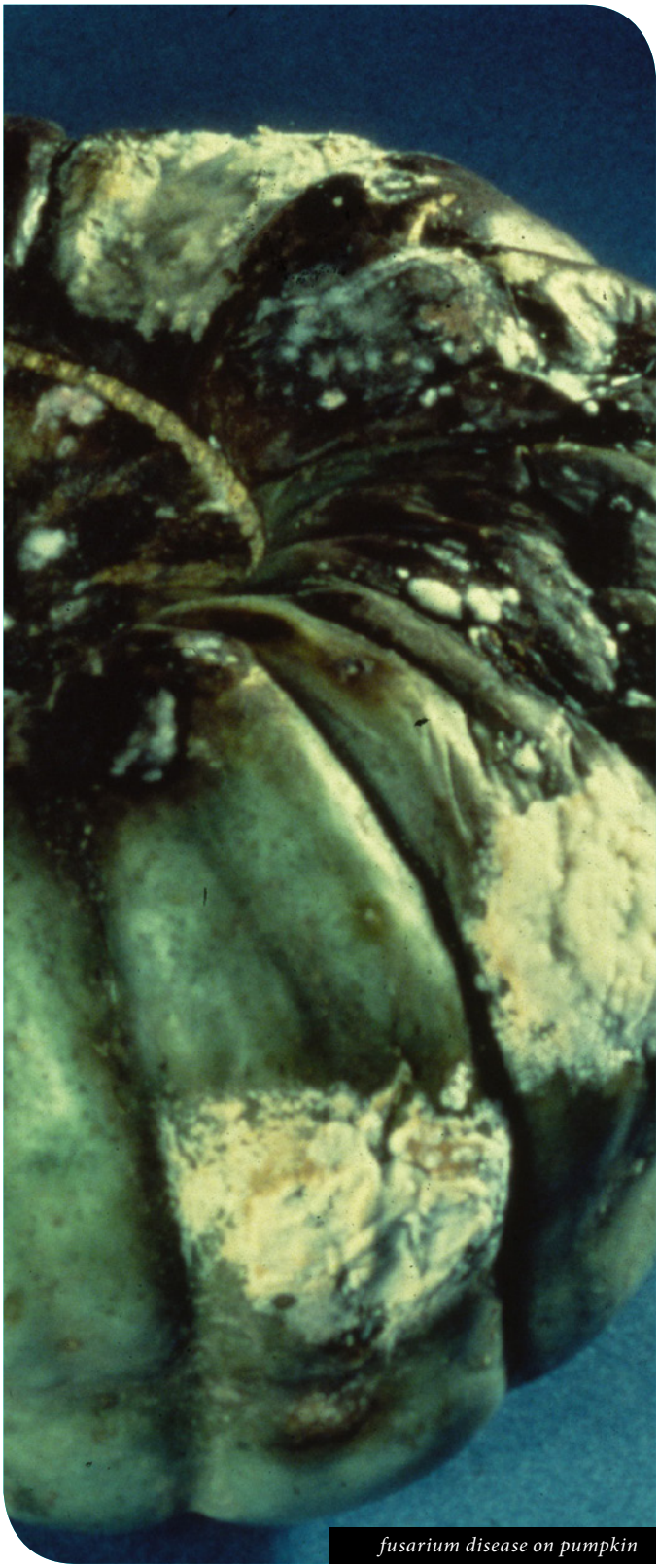
This is the tendency of the chemicals to excite insects and make them leave places where they are hiding (e.g. making cockroaches leave cracks and crevices).

Knockdown action

This refers to the chemical's ability to quickly incapacitate the insect, i.e. whether it kills quickly or not.

Phytotoxicity

This refers to the harmful effects the chemical might have on plants (e.g. some types of chemicals sprayed under certain conditions will cause burning or other damage to plant foliage, growing tips etc).



fusarium disease on pumpkin

DISEASE CONTROL

Diseases can be controlled in much the same way as insects, either by chemical pesticides, which have obvious drawbacks, or by non-chemical means such as changing environmental conditions or physically restricting the spread of disease.

The following measures are commonly practiced to control diseases in hydroponic farms:

- Sterilise the system or greenhouse between crops to eradicate disease spores. At the very least, wash with an antiseptic solution, but beware of fumes.
- Keep tools and equipment clean. Always wash after use. Sterilise tools periodically by washing with an antiseptic solution.
- Make sure shoes and hands are washed clean before entering work areas.
- Be sure that your plants are not diseased (only purchase quality, preferably guaranteed healthy stock).
- Ensure good ventilation around plant leaves and stems.
- Don't get leaves wet. It is better to irrigate with drippers or sub-irrigations. Wet foliage is more susceptible to disease.
- Trim damaged or broken plant parts with a sharp knife or secateurs. Rough or torn tissue is more susceptible to disease attack.
- Remove any diseased or dead plants or plant parts without hesitation. Often, you need to be ruthless to save the rest of your crop.

THE LIFECYCLE OF A DISEASE

Whatever method you use to control a disease, it is valuable to understand when and how it infects your crop, and what stages it goes through before and after it is a problem to you.

You may, for instance, be able to attack the disease and kill it before it even infects your crop, or you may be able to stop it from reaching your crop if you know where it comes from.

Stages in Development of a Typical Fungal Disease

1. *Inoculation*

   Inoculation occurs when the pathogen comes in contact with the plant. Any part of the pathogen which can attack the plant is called the 'inoculum'.

   If the inoculum lays dormant over winter and infects the plant in spring, this is called the primary inoculum, and it causes a primary infection. Inoculum produced from this infection is called secondary inoculum and can cause secondary infection of the plant.

   Inoculum may be present in the soil or in dead plant material near to the plant being affected; or it may be brought into the area with seed, new plants, soil, on the wheels of a car, on boots or shoes, or even carried on the wind. Inoculum can survive on weeds or infected plants nearby, and move onto cultivated plants when conditions are favourable.

2. *Penetration*

   Pathogens move into plants by breaking through the plant surface, or by entering through wounds or natural openings (such as stomata). Some fungi only penetrate trough one of these methods.

   Bacteria enter mainly through wounds. Viruses and microorganisms (microplasmas and some bacteria) enter through wounds made by vectors. (A vector is a disease carrier; e.g. aphis carry viruses. They inject their mouthpiece into the plant, creating a wound, and place the virus inside). Nematodes normally enter through direct penetration.

3. *Infection*

   This is the process by which the pathogen establishes contact with the cells or tissues that it is going to infect. In this stage, the pathogen grows and invades parts of the plant.

   Changes to the plant can be either obvious or obscure at this point. You might see discolouration or necrosis as the disease moves through the plant or it may be that the changes are microscopic and necrosis or other symptoms are not seen until the next stage (growth and reproduction).

4. *Growth and reproduction*

   The pathogen now grows and develops within the part of the plant which it inhabits. It then begins to reproduce itself.

5. *Dissemination*

   Spores or organisms produced in the growth and reproduction stage are moved to other places where they can sooner or later infect a new plant. Mostly, this dissemination is carried out by agents such as wind, water, insects, animals or man.

leaf spot fungal disease

WATER MANAGEMENT

Water Requirements

Plants need both water and oxygen in their environment. The trick to successful plant growing is often to provide the proper delicate balance between these two. Too much air usually means too little water; and too much water usually means too little air. In aggregate culture, you should usually mix a well-draining medium (e.g. gravel) with a water-retaining medium (e.g. vermiculite) to gain the required balance of water retention.

In many fruits, water constitutes 90% of the total weight; for leaves, water content is 80%, and for seeds, 10%. Apart from its role in the composition of plant parts, water is also important for the movement of nutrients into the plant and of waste products out. Everything in a plant moves in a dissolved form. If water is not constantly replaced, the cells lose turgidity and the plant wilts.

Water Excess

Symptoms of excessive water are:

- Development of leggy seedlings. This usually happens when the plants are too close together and the soil is warm and moist, as in glasshouses.
- Appearance of growth cracks (in tomato fruit, cabbage heads or carrots).
- Increased cell size.
- Long internodes (longer gaps between buds and stems).
- Bursting cells (seen under a microscope). This is usually caused by poor drainage or over-watering. Water excess can lead to stunting, die back of the top of the plant and, in extreme situations, death.

There is a greater likelihood of infection with moulds, rots and other fungal diseases in a wet situation.

Water Deficiency

Symptoms:

- The first symptom is that the growth rate reduces. Leaves become smaller (though still well-coloured).
- Stems later become slender, flowers and fruit are smaller.
- On some watery fruits (e.g. tomatoes, lemons, peaches etc) the plant sometimes draws water from half-grown fruit, causing the fruit to shrivel.
- Die back from the leading shoots can occur, followed by death in extreme cases.

A lack of water can be due to under-watering; a poor root system; excess drainage; or sometimes, extreme heat (i.e. water is sometimes evaporated out of the leaves faster than it can be absorbed through the roots in hot and windy conditions).

WATER RELATIONSHIPS

Before designing for using an irrigation system it is necessary to have an understanding of the relationship between root environments, water and plants. The root environment comprises either:

- Solid material made up of particles of varied sizes and shapes which fit together imperfectly to form a complex systems of pores and channels; or
- An enclosed environment saturated with water in either a gaseous or liquid form (or both in the case of NFT).

With a solid medium, when pore spaces are filled with water, the medium is saturated. This may occur after irrigation or rainfall. A medium will only remain saturated if excess water cannot drain freely. The amount of waster which a medium can hold at saturation depends on the volume of pore space available. This is known as the saturation capacity.

Moisture in a solid medium can be classified into three types:

1. *Gravity water* – This water can only remain in the medium for a short time before it drains out under gravity.
2. *Capillary water* – This is the main source of water for plant growth, occurring as a thin film on solid particles or as droplets in the pore space. It is held in place by surface tension. (When gravity has removed all the free water, a balance is reached where the surface tension binds all the remaining water, so that gravity is insufficient to remove it. This condition is known as field capacity).
3. *Hygroscopic water* – This is a thin film of water held so firmly to the solid particles that plants can't remove it.

Plants utilise water through a process known as transpiration. The plant acts as a pump, drawing water (against the forces holding it in the medium) into the plant roots, stems and leaves from where it is lost to the atmosphere via evaporation. (Evaporation occurs when moisture is sucked into the air, and is influenced by climactic features such a temperature, humidity and wind). If temperatures and evaporation rates are high, a plant will require more water from the medium than when they are low.

Free water is readily utilised by plants; however, increasing suction is required to remove the water held by surface tension. When plants reach a stage where they can no longer draw enough water to provide for their needs, they may begin to droop. This is known as the wilting point. If water becomes available at this stage, the plant will recover; however, if it continues without water, it will reach a point where it is beyond recovery. This is known as the permanent wilting point. The difference between permanent wilting point and the soil moisture content is known as the available water. The amount of water held and the amount that is tightly bound will vary from one medium to another.

The table below indicates soil moisture quantities for some different soils expressed as percent by weight of dry soil. This way of looking at a hydroponics medium is valuable when planning frequency and intensity of irrigations. Though the information might not be readily available for the medium you choose to use, it is worth making the effort to find out these details in the planning stages of a hydroponics venture.

SOIL TYPE	SATURATION	FIELD CAPACITY	PERMANENT WILT POINT	AVAILABLE WATER
Fine sand	15-20%	3-6%	1-3%	2-3%
Sandy loam	20-40%	6-14%	3-8%	3-6%
Silt loam	30-50%	12-18%	6-10%	6-8%
Clay loam	40-60%	15-30%	7-16%	8-14%
Clay	40-70%	25-45%	12-20%	13-20%

When to Irrigate

The zone between wilting point and field capacity is important in irrigation, with the aim being to keep moisture levels within this zone. It has been found generally that plants take most of their requirements from the upper half of the root zone and as a consequence only about half of the available water is used. Irrigations is therefore generally required when this approximate half of the available water is used up. The amount of water to be applied to a crop is therefore half of the available water in the root zone of the crop when the medium is at field capacity.

Irrigation applications are timed according to how quickly the plants use the available moisture and this is usually dependent on climatic conditions and the availability of nutrients. The rate at which water is supplied by irrigation is also important, and its governed by medium infiltration rates, i.e. the rate at which water will pass into the medium. If water is supplied at a rate greater than the medium can absorb it, runoff may occur and water may be wasted. The following table gives an indication of infiltration rates for some media.

SOIL TYPE	INFILTRATION RATE
Coarse sand	2500 mm/hr
Find sand	20-100 mm/hr
Peat	1-20 mm/hr

The ideal situation is where application rates are equal to infiltration rates.

All plants need water to grow and survive. The amount of water needed, however, will vary from plant to plant. The two main factors that affect how much water a plant needs are:

1. *The variety of the plant*

   Some types of plant have the ability to retain water within their tissues for later use. Other plants are unable to do this.

2. *The environment in which the plant is growing*

   If there is plenty of water available around the plant, it will tend to remain moister than in exposed, windy, sunny situations.

A plant can suffer from a lack of water, but it can also suffer from an excessive amount of water. When you water a plant, it is important to strike that delicate balance between too little and too much. Over-watering can be just as bad as under-watering.

red currants

Plants on Capillary Mat -nutrient solution soaks up through bottom of the pot

MEASURING WATER AVAILABLE TO PLANTS IN A SOLID MEDIUM

Calculating Field Capacity

1. Wet the medium to near saturation. Cover to prevent drying from evaporation. Let it drain for 2 to 3 days.
2. Take a sample of medium and weigh it.
3. Place the sample in an oven at 105 degrees C to dry out. Weigh and record this second weight after drying. (Do not heat at a higher temperature as this can destroy organic material and give a false reading.)
4. Calculate field capacity with the following formula:

Field Capacity = Loss in weight x 100

Final dry weight

Calculating Permanent Wilting Point

1. Fill a pot with the medium to be tested and plant a vegetable or flower seedling into it.
2. Grow the plant until its roots appear at the bottom of the pot.
3. Stop watering until wilting occurs. When the plant wilts, seal the surface of the pot with a sheet of plastic to prevent further loss of water through evaporation.
4. Now place overnight in a humid enclosure (i.e. either a humid greenhouse or plastic tent). If permanent wilting has not occurred, the plant will recover. If the wilting persists in the morning, you have then reached permanent wilting point. Weigh the medium after removing the plant and its roots.
5. Now calculate moisture content by drying the medium at 105 degrees C to find the final dry medium mass.

Available Moisture Range

Available moisture range = Field capacity minus permanent wilting point.

Estimating Water Requirements

The amount of water required by a plant is affected by a number of factors including the following:

Type of plant

Some plant varieties use more water than others. Some plants have a greater resistance to dry conditions (cacti and succulents are extreme examples).

Rate of growth

If a plant grows rapidly (perhaps because of its variety, or perhaps due to optimum growing conditions in terms of fertility, climate etc), it will use water at a faster rate.

Climate

In high temperatures soil loses water through evaporation. In windy conditions both soil and leaves of the plant lose water faster. Higher levels of natural rainfall reduce the need to irrigate. (Make sure you know not only what the annual rainfall is, but also what the distribution of rainfall is throughout the year).

Conditions in the root zone

Does the root zone drain freely? What is the medium's ability to retain water? Does the medium repel water when dry (increasing surface run off)?

CHAPTER 12 : VEGETABLE CROPS

Artichoke (Globe) Cynaria scolymus Asteraceae

Growing conditions

Perennial, needs moist conditions both in air and root environment. Does not tolerate extreme temperatures, hot dry conditions reduce the tenderness of the crop.

Nutrient requirements

Requires higher than average potassium levels.
pH 6.5 – 7.5

Suitable systems

Perlite at 25cm depth or greater gives good results.

Planting

Propagate from stem cuttings or offshoots containing roots. Seed-grown plants give unreliable crops.
Replant after five years.
Space plants at around 1 metre intervals.

Special cultural techniques

Frost protection and summer shading needed.
Normally cut back hard after harvest in late spring or summer.

Problems

Water stress causes bud not to be compact.
Pest problems can include rodents, snails, slugs, leafminers, caterpillars, aphis and birds.
Disease problems can include fusarium, botrytis and virus.

Harvest and post harvest

The swollen, immature flower bud is harvested continuously from late autumn to late spring.
Harvest when buds reach the preferred size, but before they begin to open.
Crops best in 2nd and 3rd years.

Artichoke (Jerusalem) *Helianthus tuberosus Asteraceae*

Growing conditions

Does not tolerate extremely hot conditions (though it can do well in the tropics if shaded).
Requires temperatures between 19 and 27 degrees C.

Nutrient requirements

pH 6.5
Sensitive to higher than normal levels of boron.
Nutrients as for globe artichoke but much higher phosphorus.

Suitable systems

Does very well in aggregate culture (particularly sand).
Not suited to rockwool or water culture.
Perlite at a minimum depth of 25 cm gives good results.

Planting

Plant divisions at 35 – 40 cm spacings late winter.

Special cultural techniques

Shade in very hot weather.
Pull media up around stems periodically as it grows to ensure tubers are well covered.
Remove flowering shoots.

Problems

Fungal rots, particularly *Sclerotium rolfsii*, are difficult to control once they attack.
Pests are rarely serious.

Harvest and post harvest

Harvest 3 to 4 months after planting when foliage dies down.

Asparagus *Asparagus officinalis Liliaceae*

Growing conditions

Grows best at temperatures between 15 and 25 degrees C.
Requires deep, well aerated medium.

Nutrient requirements

Heavy feeder requiring a higher than average EC.
Phosphorus and potassium should be at high levels.
pH 6.0 – 6.8
Has a high boron requirement.

Suitable systems

Asparagus needs to be planted deep.

Aggregate culture is best in a bed at least 25cm deep.
Coarse sand has been successful.
Sutherland recommends perlite for good results.
Media must be well aerated.
Gravel culture is considered suitable.
Maxwell suggests no advantage over soil, therefore limited commercial prospects.

Planting

Propagated by seed or division.
Seedlings take 2-3 years before the first harvest. Lift seedlings during dormant period (winter), trim roots, cut off remains of old leaf stalks and store in moistened peat moss until buds begin to swell (late winter/early spring), then transplant into hydroponic media spacing plants 15 cm apart.

Special cultural techniques

Intercropping in first 2 years while plants are establishing.

Problems

Occasionally aphis, white fly and caterpillars can be a minor problem.

Insect damage is rarely serious.

There are relatively few fungal problems. In some places crops are sprayed with copper fungicides (e.g. Bordeax or Kocide) to prevent fungal diseases.

Harvest and post harvest

Yield per unit area is relatively low making it less suitable for commercial hydroponics than other crops.

Aubergine *see Eggplant*

Bamboo Shoots

Cultivation of bamboo for food production is considered a highly specialised art in Japan. Bamboo can take up to seven years from planting to reach harvestable stage. New shoots for harvest must be covered to prevent them becoming bitter. Bamboo is a rhizomatous plant and can spread very vigorously.

Commercial hydroponic production of bamboo is at least very rare, although some home hydroponic growers have experimented with it. Its intolerance to 'wet feet', along with its potential to spread vigorously, limit the suitability of bamboo as a hydroponic crop.

bamboo shoots

Bean (Common) Phaseolus vulgaris Papillionaceae

Growing conditions

Needs plenty of moisture.
Never let it become waterlogged.

Nutrient requirements

Regular supply of nutrient will result in rapid growth and early cropping.
Phosphorus, potassium and sulphur levels high but nitrogen not as high as with other vegetables.
The ratio of nitrogen to potassium should be roughly equal.
Sensitive to excessive boron.
EC should be around 4.0mS/cm early in the crop, decreasing to 2.0 at harvest.
Yields decrease significantly at high EC levels close to or after flowering.
pH is best around 6.0 and never below 5.5.

Nutrient solution as follows:

NUTRIENT	PPM
Nitrogen (as nitrate)	180 – 270
Phosphorus	40
Potassium	210 – 350
Calcium	140 – 200
Magnesium	30 – 45
Iron	3
Copper	0.05
Molybdenum	0.05
Manganese	0.05
Zinc	0.05
Boron	0.05

Suitable systems

Beans yield prolific crops under hydroponic systems – at the height of the season, the first beans are ready for picking 8 to 9 weeks after sowing. While all varieties perform well, climbing varieties offer the advantage that they do not take up as much room.

Most aggregate media 10 cm or more deep give excellent results.
NFT, sand, sawdust and most aggregate systems which have been tried have been successful.
Seeds have been germinated in NFT.
Maxwell suggests sand and perlite.
In the Netherlands, yields of climbing beans in rockwool have been better than in soil. Slabs used where 7.5 cm deep and 15 – 20 cm wide with 4 to 5 plants per slab. Slabs were heated at 15 to 18 degrees C in the early stages.

Planting

Seeds should be sown singly, ata spacing of 10 cm between seeds.
pH levels should be maintained at 6.0; pH below 5.5 will significantly affect growth during early stages.

Special cultural techniques

Trellis is needed, particularly for climbers which can grow up to 2.5 m tall.

Pests

Red spider – minute insects on the underside of leaves, which cause leaf mottling and eventual death. They can be detected by the presence of a reddish tinge or webbing under the leaf. Spray with malathion; alternatively a population of predatory mites could be released into the greenhouse.
Bean fly – larvae of this fly cause damage to the plant by burrowing into the stems. Control by spraying with malathion.
Thrips – These tiny insects reduce pod set by damaging the flowers. Spray with malathion.

Diseases

Mosaic viruses pose a significant problem to bean growers. There are several strains which can infect the plant via aphis transmission. The common mosaic bean virus causes new leaves to crinkle and stiffen; older leaves have chlorotic mottling and underturned margins. There are no satisfactory remedies for viral diseases, however mosaic-resistant varieties have been developed.

Varieties

Different varieties need different temperature conditions.
Flat pod varieties (e.g. Kwintus) have been grown successfully in the Netherlands in rockwool.

Beetroot *Beta vulgaris* Chenopodiaceae

Growing conditions

It will grow in semi-shade (making it adapted to intensive culture). Full sunlight is not necessary, but reasonable light levels are preferred.

Nutrient requirements

Needs a good supply of potassium and calcium.
Will also use chlorine and sodium more than many other plants.
Has a high boron requirement (0.25 ppm or higher).
Responds to high levels of manganese, copper, iron, and molybdenum.
pH 6.0 to 6.5.
Will tolerate very high EC levels (over 5.0 mS/cm).

Suitable systems

Can give excellent results in most aggregate culture medium (minimum depth of 10 cm) though not any better than in soil culture.
Some suggest it takes too much space and too long to grow in hydroponics.

Planting

Sow seeds direct, using twice as much seed as will be needed, into aggregate culture. Seedlings should then be thinned to a spacing of 15 cm X 30 cm between rows.
Germination rates can often be poor.
They can be started in sand and transplanted when 6 – 8 cm high, though transplants might not grow as well as plants sown direct.

Problems

Pest and disease problems are minimal.

Harvest and post harvest

Commercial viability is unlikely in hydroponics.
Harvesting of large, tender roots can be done nine to ten weeks after initial sowing.

Broad Bean *Vicia faba* Papillionaceae

Hydroponic culture doesn't give any better result than soil.

Growing conditions

Hot, dry weather reduces cropping.

Nutrient requirements

Similar to common bean.
Tolerates higher levels of boron than the common bean.
pH 6.0 – 6.5

Suitable systems

Aggregate culture gives very good results, but not discernably better than soil culture.
Media should be 15 cm or more deep.
Not considered suitable for commercial growing.

Planting

As for common bean.

Special cultural techniques

Trellis required.

Shading may be needed.

Problems

Aphis can damage tip growth (control with pyrethrum near to cropping, control with malathion early in the season).
Excess moisture can cause root rot.
Harvest and post harvest

3 to 4 months after planting.

Broccoli *Brassica oleraceae –Botrytis group* Cruciferae

Broccoli is easier to grow in hydroponics than other brassicas.

Growing conditions

Sensitive to poor aeration – hence best in the better draining media with more frequent than normal applications of nutrient.

Nutrient requirements

Good levels of nitrogen and phosphorus during development.
Iron is also important
Has a high boron requirement (0.25 ppm is suggested).
Heavy feeders, requiring a higher than normal EC (up to 3.5 mS/cm early in the crop and up to 3.0 mS/cm at maturity).
pH 6.0 to 6.8.

Suitable systems

Most systems are suitable. Aggregate systems are probably best.

NFT growpots have been used successfully.

Planting

Seeds can be sown direct or in tubes of perlite which can later be sat in NFT channels.
Spacing should be 30 X 30 cm.

Special cultural techniques

Plant support is necessary, and may be critical if there is wind exposure.

Problems

Grubs can be a serious problem in the heads – pest control is essential.

Harvest and post harvest

Broccoli heads should be ready for picking 9 to 11 weeks after planting and will bear for a further two to three months.
The heads should be picked well before there is any sign of flowering and should be cut with 5 cm of stalk attached.

Brussels sprouts *Brassica oleraceae – Gemifera group Cruciferae*

Growing conditions

Brussels sprouts require cool to cold (i.e. frosty) weather to develop adequate, tightly-formed hearts.
Need a well-aerated medium and frequent irrigations.

Nutrient requirements

Nitrogen, phosphorus and iron are particularly important.
Have a high boron requirement.
Recommended EC of 3.0 mS/cm while establishing, reducing to 2.5 mS/cm when cropping.
pH 6.5

Suitable systems

Media 10 cm or more deep.
Some consider these plants too large for commercial hydroponic growing.

Planting

Direct sow seeds or plant from tubes in late summer.
Final spacing should be 45 X 45 cm between plants

Special cultural techniques

Some form of support or trellising is essential.

Problems

Amateur gardeners frequently have difficulty getting a clean crops.

Harvest and post harvest

Brussels sprouts take up to seven months to mature. Hearts should be harvested when they are still small and firm as flavour is lost when they mature and open up.

brussels sprouts

Cabbage *Brassica oleraceae – Capitata group* Cruciferae

Growing conditions

Aeration should be very high.
Constant moisture is important.
Ideally temperatures above 13 degrees C at all times.

Nutrient requirements

Nitrogen, phosphorus and iron are particularly important.

Has a higher than average boron requirement.
EC at around 3.0 initially dropping to 2.5 later.
pH 6.5 to 7.0

Suitable systems

Excellent results from aggregate culture.
Should suit most aggregate culture.
Minimum aggregate depth of 10 cm.
Has been successfully grown on a bench system, similar to lettuce.
Good results have also been obtained from NFT systems.
Compared with soil, production is not normally high enough to justify commercial hydroponic growing.

Planting

Smaller varieties can be sown at a distance of 30 X 30 cm between plants.

Larger varieties will need to be spaced 45 X 45 cm apart.

Special cultural techniques

Trellising is not required.

Problems

Cabbage white butterfly grubs must be controlled.
Other pests can include aphis, flea beetles, maggots and cutworm.
Diseases will be better controlled in hydroponics than in soil; however cabbage can be attacked by several fungi including fusarium, downy mildew and alternaria leaf spot.

Harvest and post harvest

Cabbages can be stored for a month or more after harvest at 0 to 3 degrees C and low relative humidity.

Varieties

There are varieties available to crop at all times of the year

Capsicum *Capsicum annum var. annum* Solanaceae

Growing conditions

Optimum temperatures for fruit development are 22 -23 degrees C by day and 18 – 19 degrees C at night.
Vegetative growth is best at temperatures between 25 and 30 degrees C.
Strongly-growing plants can withstand high temperatures (i.e. over 30 degrees C) although 35 degrees C and above are harmful.
Humidity levels should be maintained at around 75%. Lower levels of humidity may cause flower abortion while higher levels encourage botrytis problems.
Semi-shade is not only tolerated but desirable in warm areas.

Nutrient requirements

Capsicums require a soil pH of 6.0 to 6.5.
Growth is best if the EC reading can be kept low (but still supplying adequate nutrition).
Initially a ratio of 4 parts nitrogen to I part phosphorus to 5 parts potassium will encourage a higher potash formula to encourage flower formation, e.g. NPK 5:1:10.
Supply nitrogen as nitrate. Do not use ammonium form.
Calcium, magnesium and boron levels should be higher than normal.

Suitable systems

Aggregate systems with most media, 10 cm deep, give excellent results.
Black poly bags filled with sand and drip irrigated have been very successful.
Perlite/sand mix or straight perlite in foam boxes or beds have also given good results.
Rockwool slabs have given excellent results.
While some people claim success with NFT, this method is generally unsuitable for commercial production.

Planting

Seedlings are planted at 30 to 40 cm spacings.

Special cultural techniques

Early forming flower-buds are removed to encourage initial vegetative development. The plant should be at least 40 cm tall before flowers are allowed to develop.
Capsicums require a support system. There are two methods which can be used:

Problems

Early forming flower buds are removed to encourage initial vegetative development.
The plant should at least be 40 cm tall before flowers are allowed to develop.
Capsicums require a support system. There are two methods which can be used:

1. Vertical string supports

   Only 3 – 4 leaders per plant are allowed to grow up the string; side shoots are suppressed at the first or second leaf stage. If a double planting density is used, only 2 leaders per plant are used.

2. Horizontal Nets

   Nets with a mesh size of 20 cm are used to support the plants. Nets should run every 30 cm with the lowest being 50cm above the floor. Side shoots do not have to be suppressed under this method.

Harvest and post harvest

Strong winds can be a serious problem.
Insect pests can include aphis, weevils, maggots, flea beetles, leaf miners and caterpillars.
The most serious diseases are virus problems which are transmitted by aphis (for this reason aphis control is important).

Carrot *Daucus carota var. sativa* Apiaceae

Carrots are frequently difficult to grow in hydroponics (because roots don't form as well as in soil) though I have seen occasional success achieved by hobbyists.
Short-rooted varieties are much easier in hydroponics than others.

Growing conditions

Warmth, good drainage and good aeration are essential.

Nutrient requirements

Minimise nitrogen and maintain good levels of phosphorus and potassium.
If you lower levels of calcium nitrate to minimise nitrogen you will also reduce calcium supply. To compensate you must supply additional calcium in some other way.
pH 6.3
EC should never go above 2.0 mS/cm

Suitable systems

Aggregate culture is the only worthwhile method. Coarse or heavy media do not succeed.

A medium such as 30% vermiculite and 70% perlite may give the best result.
A deep bed is required.
Sutherland reports excellent results with perlite 15 to 30 cm deep though other authorities report failure in perlite.
Carrots are not a viable commercial crop in hydroponics.

Planting

Sow direct into vermiculte/perlite bed or sand/vermiculte bed.

Problems

While pest and disease problems are relatively few, aphis and leaf hoppers can occur and several fungal diseases can arise from time to time, particularly in excessively wet conditions.

Harvest and post harvest

Carrots can be lifted at any stage of growth.
In a home hydroponic garden, thinning to allow some carrots to grow bigger will yield smaller carrots to eat.

capsicums

Celery *Apium graveolens var. dulce* Apiaceae

Growing conditions

Prefers cool or part-shade in warmer months.
Good aeration is essential.
Optimum day temperatures are 16 to 21 degrees C. Temperatures below 10 degrees C can cause seed stalk development.

Nutrient requirements

A good level of nitrogen is essential.
Taste is improved by adequate supply of chlorine and sodium.
Has a higher than average boron requirement.
pH 6.5

Suitable systems

Good results in most media in aggregate culture (minimum depth of 10cm).
NFT culture has also given good results in non-commercial systems.
Rockwool slabs have given excellent results.
Commercial viability of celery in hydroponics is questionable.

Planting

Space 12 cm apart

Special cultural techniques

Plant densely to create a blanching effect while growing. Wrap stems in paper or black plastic for 1 month before harvest to blanch.

Problems

Subject to many different pests, diseases and other disorders.

Harvest and post harvest

Force cool quickly as soon as possible after harvest.
Storage at 0 – 4 degrees C and 90% humidity extends the shelf life considerably.

Chicory *Cichorium intybus* Asteraceae

Chicory is sometimes commercially grown in hydroponics in any of the following ways:

1. Dormant crowns grown in the ground are planted in hydroponics and sprouted – the large head of leaves which emerges is harvested before it bursts open and eaten as a salad vegetable.

2. Seedlings are grown from the beginning in hydroponics to produce crowns which are eaten as a salad vegetable.

3. Seedlings are grown in hydroponics to produce roots which are cooked and eaten like carrots.

Growing conditions

Sprouting crowns: keep at 13 to 15.5 degrees C and in total darkness until the shoots are approximately 18 cm tall, then harvest.

Nutrient requirements

Similar nutrient formulae to lettuce.
pH 5.5 to 6.0.

Suitable systems

NFT or semi-NFT (i.e. NFT with the gullies filled with gravel).
Aggregate: must be well aerated and constantly moist.

Planting

Sow seeds in trays or boxes of 60% sand and 40% vermiculite.
Transplant to permanent position later in soil or gravel bed. Grow to maturity.
If grown in soil, lift growns and trim off any side shoots.
Store at temperatures between 0 and -5 degrees C for several weeks.

This cold temperature stimulates development of the flower buds. Wash then transplant into hydroponic media. Maintain a higher temperature in the root zone than in the air above i.e. 15 to 20 degrees C in the root zone and 12 to 17 degrees C in the air. The primary flower bud develops quickly, swelling to 6 to 8 cm and weighing up to 120g in 3 to 4 weeks, at which time it is harvested

Harvest and post harvest

Harvested shoots which are thoroughly blanched have the best flavour.
Flavour deteriorates as the harvested shoots turn green.

Corn (Sweet) *Zea mays var. rugosa* Poaceae

cauliflower

Nutrient requirements

Heavy feeding is required during establishment.
pH 6.0
An EC of 2.5 mS/cm or higher can reduce yield.

Suitable systems

Aggregate – most media should succeed at a minimum depth of 15 cm.
Success has been reported in sand beds.
NFT systems have also given good results.
Yields are relatively low per cubic metre and commercial application in hydroponics is questionable.

Planting

Sow direct into aggregate or into rockwool propagating blocks.

Problems

Corn is prone to attack by a range of insect pests, fungi, bacterial and virus diseases.

Harvest and post harvest

Harvest when kernels reach full size and turn yellow. This is best determined by examining directly.
Flavour deteriorates rapidly after harvest. For best flavour eat within 2 hours of harvesting, or freeze on harvest.

Cucumber *Cucumis sativis* Cucurbitaceae

Growing conditions

Needs day temperatures of 24 – 30 degrees C. Tolerates over 38 degrees C.
Requires high levels of water (i.e. needs frequent irrigations and prefers high humidity).
Semi-shade may be necessary in warm climates or mid summer.

Nutrient requirements

pH should be around 5.5.

In general, a standard nutrient solution with a ratio of approximately 4 nitrogen to 6 potassium to 1 phosphorus will give good results.
Ratios between nutrients should be maintained approximately as follows during all stages of the crop:

- 2 parts K to 1 part ca
- 10 parts K to 1 part Mg

The only variation might be a slight increase in the proportion of potassium during fruit formation and development. While maintaining the nutrient ratios you should vary the amount of nutrient powder you dissolve in solution at different stages of the crop to achieve EC readings as follows:
Early while the plants are establishing: 2.0 mS/cm.
From when the plants reach about 1 metre tall until 3 to 4 weeks after the first harvest: 2.5 mS/cm
Between 3 and 7 weeks after the first harvest: 2.0 mS/cm
Beyond 7 weeks after the first harvest: 1.7 mS/cm
An EC of 3.0 mS/cm has been found to reduce crop yield.
Keep sodium and chlorine levels as low as possible.
Over 50 ppm sodium can cause problems.
Sulphur is best kept between 30 and 60 ppm.
Nitrogen should be as nitrate and not ammonium.
Iron is needed at higher levels (up to 3 ppm) early in the growing season, but can be reduced as the plants mature.

Suitable systems

Aggregate culture is successful in most media at 10 to 15 cm depth.
Perlite has been successful in commercial production.
NFT systems have also given excellent results but are not as successful as aggregate culture commercially because roots can clog the gullies and impair flow of nutrient solution.
Rockwool has been used commercially in the Netherlands and the UK.

Planting

Seed can be started in rockwool or sand and transplanted.
Direct seeding is effective because seeds are so large.
Space plants 15 cm apart.

Special cultural techniques

Pinch out terminal buds to encourage branching and stimulate female flower development. (Note: male and female flowers are separate but on the same plant).
Applications of silver nitrate and gibberellic acid will promote male flowers. Ethephon will promote female flowers.
Trellising is required. Be careful tying stems as they can be brittle.

Problems

Wind protection may be necessary.
Diseases include powdery mildew and downy mildew, anthracnose, fusarium wilt, scab, alternaria leaf spot, bacterial wilt and several virus diseases.
Pests include cucumber beetle, squash bug, leaf miner, leaf hoppers, aphis and spider mites.

Harvest and post harvest

Once in production, a crop is picked every one to three days.
Quality in terms of colour and seed size deteriorates if fruits are allowed to get too large.
Cool and store between 7 and 10 degrees c on harvest (colder temperatures can damage the fruit).

Varieties

New mildew resistant strains are easier to grow.
More compact-growing types such as apple cucumbers are more adaptable to hydroponics, though other types have been grown commercially with success.

Endive *Cichorium endiva* Asteraceae

Growing conditions

Well suited to hydroponic culture.
Similar growing conditions to Chicory.

Nutrient requirements

As for chicory.
pH around 5.5.

Suitable systems

NFT pipe systems have given good results.
Aggregate culture has also been successful.

Planting

Similar to lettuce.

Special cultural techniques

Blanched by tying leaves up to stop light reaching the centre or 'heart' of the plant.
Blanching reduces bitterness of the crop.

Harvest and post harvest

Cut at ground level and remove outer green leaves at harvest.

Eggplant *Solanum melongena* Solanaceae

Growing conditions

Needs warmth and low humidity.
Roots require good aeration and drainage but constant moisture and nutrient supply in the root environment.

Nutrient requirements

Basic nutrient should be similar to that used for tomatoes.
Nitrate deficiency decreases yield.
Nitrate excess also decreases yield and causes high nitrate levels in the fruits.
Cut nutrient solution concentration by around 30% as soon as fruits are seen to be forming. Return to normal feeding after harvest (you may well have several harvests in one season).
Optimum nitrate levels are 6-8 mg/litre, under greenhouse conditions in southern France.
EC should be around 2.0 mS/cm.
pH 6.0

Suitable systems

Growing on rockwool slabs has given a significantly increased production over soil cultivation (i.e. 10 cm deep slabs and 2 plants per 90 cm slab).
Maxwell suggests rockwool, NFT and aggregate culture as being commercially viable.

Planting

harvesting eggplant

Higher summer temperatures are needed to initiate bulb or clove formation.

Nutrient requirements

Similar to onions.
pH 6.0.

Suitable systems

Most types of aggregate are successful with a minimum of 10 cm depth.
Maxwell suggests sand culture.
Sutherland reports good results in rockwool slabs, though this may be questionable for commercial use due to the danger of rockwool fibres adhering to cloves when harvested.

Planting

Divide and plant cloves in spring.

Problems

Aphis can attack foliage.
Fungal rots can attack roots and cloves in over-wet conditions.

Harvest and post harvest

Lift autumn-planted crops in early autumn and spring planted crops in late autumn (N.B. It can take up to 10 months from planting to harvest).
Store in a dark dry lace after harvest.

Kale *Brassica oleracea var. sabellica* Brassicaceae

Kale is somewhat similar to cabbage. It can be expected to grow under similar conditions and have similar nutrient requirements.
Aggregate cultures are likely to give the best results.
Kale plants can reach heights of 50cm and may require support structures.

Leek *Allium ampeloprasum* Amaryllidaceae

Growing conditions

Similar to onions, but a cool season crop, planted in summer for winter maturity.

Nutrient requirements

Heavy feeders needing frequent applications of nutrient solution.
Phosphorus is most important, nitrogen next in importance and phosphorus next.
pH 6.5 to 7.0

Suitable systems

Aggregate gives excellent results in most media 10 cm or deeper.
Perlite gives good results.
Good results have been reported on rockwool slabs.

Planting

Sow seed into perlite or rockwool propagation blocks.

Special cultural techniques

Cutting the tap root will reduce chances of plants going to seed in warm conditions.
Blanched by placing a collar, or tying paper around the stem.

Problems

Similar to onions.

Harvest and post harvest

Six to seven months from planting to harvest.

Lettuce *Lactuca sativa* Asteraceae

Growing conditions

Growth needs to be fast and at an even rate (will mature in 40 – 85 days depending on variety).
Shading may be needed in hot conditions.
The root zone should never overheat.

Most varieties prefer temperatures between 12 and 20 degrees C.
Temperatures over 27 degrees C can affect quality and cause

red kale

Suitable systems

Vertical columns have been used in Poland.
NFT has been used in England, Japan, and Australia.
Modified NFT with gravel in gullies is very successful.
Coarse aggregate culture gives excellent results in any medium 10 cm deep.
Rockwool gives excellent results and has been used commercially.
Media with a greater cation exchange capacity are not suitable.

Planting

Germinate seed in vermiculite, perlite or rockwool propagation blocks, then transplant into system at 6 to 8 leaf stage.
Sow direct into aggregate beds then thin out.
Some growers buy in seedlings. This accelerates the crop turnover time and reduces labour, but there may be tradeoffs in quality, availability, or varietal choices.

Special cultural techniques

Remove marked or damaged outer leaves.

Problems

Irregular burst of growth can cause decreased quality or quantity of produce.
Rapidly-grown lettuces are relatively free of disease.
Excess water or poor aeration commonly causes yellow or rotting of the lower (outer) leaves.
Some will burn on leaf tips if exposed to too much sunlight.
Pests include aphis, flea beetles, crickets, springtails, leaf hoppers, caterpillars, whitefly, slugs and snails.
Aphis is of particular concern because it transmits viral diseases.
Other disease problems include damping off (pythium), sclerotinia, downy mildew, powdery mildew, botrytis, rhizoctinia, and anthracnose.

Harvest and post harvest

Lettuce are ready to pick after four weeks in summer.
Rockwool grown plants can be harvested with roots intact, still in the rockwool – this significantly improves the keeping quality.
Damaged or marked leaves should be removed at harvest.
Lettuce should be cooled rapidly after harvest, in order to maximise shelf life.
Store at between 2 and 4 degrees C under high humidity.

Varieties

Hydroponics is especially suited to the production of the small, fancy leaf type lettuces. Commercial growers will find it necessary to source varieties for different seasons.
Mignonette can be grown all year (with the aid of a greenhouse in cooler climates).
Some varieties are slower bolting, reacting more slowly to higher temperatures. These are most suited to grow in warmer months.

Marrow

Vegetable marrow, squash etc *see* zucchini (treat similarly).
Spaghetti marrow is not as good as other types, according to Sutherland.

Melon *Cucumis melo* Cucurbitaceae

Growing conditions

Hot, dry air environment with frequent irrigations.
Root zone should never dry out.
In hot weather each plant can use as much as 4 litres of water per day.
In cool temperature climates substrate warming (to 25 degrees C) is used to start greenhouse crops early in the season.

Nutrient requirements

EC should be kept around 2.0 to 2.5 mS/cm early in the season, then 2.5 or slightly higher once plants have established. An EC of 3.0 or higher can reduce crop yield.
Nutrient solution should be applied at a rate to allow about 20% of each irrigation to run off and be lost. This helps wash away any build-up of sodium, which can be a problem.
Potassium should be increased a little during fruit development.
Nutrition requirements are similar to cucumbers.
pH 5.5 to 6.0

Suitable systems

Rockwool slab culture tends to produce a larger number of smaller fruit than soil culture (for this reason, larger fruiting varieties are preferred in rock wool). Melons are grown commercially in rockwool in the Netherlands.
Good results in aggregate culture, most media at 10 cm deep.

Planting

Spacing depends on variety.
Seed direct into perlite or rockwool or transplant seedlings.

Special cultural techniques

A plastic collar or mulch between the media and the foliage will help keep air humidity down.
Keep fruit from sitting on moist surfaces.
Trellis must be used to control direction of growth.

Problems

Pests can include aphis, cutworms, leafhoppers and spider mites.
Diseases can include powdery and downy mildew, fusarium and anthracnose.
May need hand pollinating.

Harvest and post harvest

Rock melons are picked when the fruit comes away from the stem easily. They are at their best three days later, after storage at 21 degrees C.
Watermelons are ripe when the surface of the fruit becomes slightly bumpy and the underneath becomes slightly yellow.

Varieties

Honeydew melon *Cucumis melo* – Inodorus group
Rock melon, cantaloupe or musk melon *Cucumis melo* – Reticulatus group.

Okra *Abelmoschus esculentus* Malvaceae

Growing conditions

Need good aeration and drainage.
Requires frequent irrigations.

Needs ample warmth (around 24 to 26 degrees C).

Nutrient requirements

Good nitrogen supply important.
Okra is a heavy feeder.
pH 6.5.

Suitable systems

NFT used in Australia.

Planting

Soak seeds in water for two days before sowing.

Special cultural requirements

Requires support system.

Problems

Verticillium wilt is a particularly serious problem. Several other fungal diseases can occur, including fusarium wilt and some leaf spot fungi.
Aphis and a number of other insect pests may present a problem.

Harvest and post harvest

Harvest daily starting 8 to 10 weeks after planting. If pods are allowed to stay on the plant after they attain full size (i.e. 10 to 15 cm long) quality deteriorates fast.
On harvest, rapidly cool and store at 7 to 10 degrees C and 90% humidity. Lower temperature can injure the fruits.

Onion *Allium cepa* Amaryllidaceae

Growing conditions

A relatively dry situation – low humidity, good drainage and aeration and minimum irrigations.
Requires good air movement around foliage to minimise fungal problems.

Nutrient requirements

High levels of potassium and nitrogen.
pH 6.0 to 7.0
Manganese, copper, zinc and molybdenum are important micronutrients.
Tolerates high levels of boron but only has a moderate boron requirement.
N:P:K ratio of 15:3:16.
Reduce nitrogen and potassium levels as the crop develops. By mid-season nitrogen levels should decrease by 20%, and by the end of the season by 30%. Potassium can be dropped by up to 20% over the total life of the crop.
EC should never go above 1.8 mS/cm.

Suitable systems

Aggregate culture gives excellent results, though not significantly different from soil culture.
Most media should be around 10 cm deep.
Bulb onions take too long in hydroponics, given the crop's value.
Spring onions are quicker and may be viable in perlite, sand or modified NFT (with gravel in the gullies).

Planting

Seed can be germinated in aggregate culture, or pre-germinated seedlings transplanted into the system.

Special cultural techniques

Cease irrigations on bulb-forming onions when bulb has attained full size.
Allow the tops to almost completely die down, then lift and store.
The weed free nature of hydroponic production may provide some advantage over soil-grown onion crops in terms of labour.

Problems

Too much water causes fungal problems.
Pests include aphis, thrip, maggots and cutworms.
Diseases include downy mildew, fusarium, botrytis, smut and several other virus and fungal problems.

Harvest and post harvest

Lift bulb onions after tops die down completely.
Pull spring onions before the tops begin to die down.

Pak-choi *Brassica rapa* –Pekinensis Group Cruciferae

Growing conditions

Requires a lot of moisture, but reasonable drainage also.
Growth ceases at temperatures below 10 degrees C.

Nutrient requirements

EC 1.5 to 2.0 mS/cm
pH 7.0
Otherwise similar nutrition to cabbage.

Suitable systems

Rockwool slabs have proven successful.
NFT or modified NFT with gravel could be worth trying.

Planting

Can suffer transplant shock.
It is preferable to allow it to germinate in its permanent position.

Problems

As for cabbage.

Harvest and post harvest

Harvest 70 to 80 days after planting.

Parsley *Petroselinum crispum* Apiaceae

Growing conditions

Tolerant of cold temperatures.
Good aeration but constant moisture in the root zone.

Nutrient requirements

Similar to carrots.
pH 5.5 – 6.0

Suitable systems

Excellent results in 30% perlite / 70% coarse sand at 20cm depth.
NFT has been used but root rots are sometimes a problem.
NFT, rockwool and most aggregate systems have been suggested by various hydroponics experts.

Planting

Space at 10 to 20 cm intervals.

Problems

Few pest and disease problems.
Some insects can mark foliage occasionally.

Harvest and post harvest

Cut 70 to 80 days from planting.
Plants can be repacked several times over a season, then replanted for the next year.
Store at 0 to 4 degrees C and high humidity.

Parsnip *Pastinaca sativa* Umbelliferae

Growing conditions

Requires a very deep medium.
Generally unsuited to hydroponics, though some have had success in aggregate culture.
Tolerates cold and frosts.

Nutrient requirements

Phosphorus is needed for good root development.
Calcium, nitrogen and potassium are needed in larger than normal proportions.
pH 6.0

Suitable systems

Commercial viability is highly questionable.
Sutherland reports excellent results in perlite 25 cm deep.

Planting

Sow seed in perlite.

Pea *Pisum sativum* Papillionaceae

Growing conditions

Requires good aeration, low humidity and frequent irrigations with nutrient solution under warm conditions.

Nutrient requirements

Calcium, iron and phosphorus are particularly important.
Adequate manganese is essential to achieve maximum cropping.
pH 6.0 to 7.0
I suggest trying an NPK ratio of 8:1:5.

Suitable systems

Aggregate culture should succeed with most media at a 10 cm depth, or rockwool.
Not generally suited to NFT (though we have had snow peas

parsley

P

Growing conditions

Tubers must not be exposed to light.
Media should not become too warm, though foliage can withstand heat.
Media must be deep (30 cm or deeper).
Good drainage and aeration are essential.
Some claim potatoes need a shorter growing period in hydroponics compared with soil.

Nutrient requirements

Heavy nutrient requirement.
Requires higher levels of phosphorus, otherwise similar nutrition to tomatoes.
pH must be 5.0 to 6.0.
EC ideally between 2.0 and 2.5 mS/cm.
NPK 7:1:9 (N.B. higher phosphorus than other vegetables).
Heavy feeders, but because they are sensitive to high EC levels, frequent applications of nutrient solution in a very well-drained system will give the best results.

Suitable systems

Aggregate culture or granulated rockwool only are suitable.
NFT or rockwool slabs are unsuitable.
Potatoes grow easily in 50% sand and 50% perlite.
Not suited to commercial hydroponic production.

Planting

Plant sprouting pieces of tuber direct.

Special cultural techniques

Media must be continually pulled up to cover any exposed tubers.

Problems

Prolonged absence of copper in nutrient reduces reproduction of aphis.
Increased zinc in solution also reduces aphis.

Harvest and post harvest

Harvest when tops begin to die down.
Red-skinned varieties have a better keeping quality.

Pumpkin *Cucurbita pepo var. pepo* Cucurbitaceae

Growing conditions

Similar to cucumber but slightly lower temperature requirement.

Nutrient requirements

pH of 5.5 to 7.5.
Nutrition similar to cucumber.

Suitable systems

Rockwool very successful.
NFT channels can become clogged with the large root system, reducing flow of system.

Planting

Sow seed direct in perlite, rockwool or sand; or transplant seedlings.

Spacing depends on variety.

Special cultural techniques

Trellis is generally required.

Problems

Similar to cucumbers.

Harvest and post harvest

Harvest when fruit stem begins to shrivel. Remove fruits by cutting.
Store at 0 to 10 degrees C.

Varieties

There is considerable variation in growth habit from more compact bushes to very large sprawling plants.

Radish *Raphanus sativus* Cruciferae

Some growers have found radishes difficult in hydroponics but very easy in soil. Some have been successful with aggregate culture.

Growing conditions

Shade is needed in hot areas.
Aeration is important.

Nutrient requirements

Nitrogen and phosphorus are important.
Iron is often difficult to absorb due to lack of fine root hairs. Iron is important.
Sensitive to low levels of manganese.
Higher than average boron requirement.
pH 6.0 to 7.0.

Suitable systems

Most aggregate media 10 cm deep, perhaps best in perlite, gravel, sand.
Not suited to rockwool or NFT.

Planting

Sow seed direct.

Problems

Excess warmth can cause bolting.
Pests and disease similar to turnip.

Harvest and post harvest

Usually 4 to 6 weeks from sowing seed.

Rhubarb *Rheum rhabarnarum* Polygonaceae

Growing conditions

Temperatures below 25 degrees C.
The root environment should be well aerated but with a constant supply of water and nutrient.

Nutrient requirements

Nutrition must be maintained at reasonable levels at all times.
Phosphorus is particularly important.
pH 5.5 to 6.0

Suitable systems

Aggregate culture gives excellent results with most media at 15 cm depth.
Rockwool slabs have been used successfully.
If in NFT, channels must be very wide.

Planting

Plant so the crowns barely appear above the surface of the medium.
Propagated by division.

Special cultural techniques

Shading is sometimes used to get crops in warmer weather.

Problems

Frost ad a few fungal rot diseases are the only major problems.

Harvest and post harvest

When leaves turn down on the leaf stem they should be removed by pulling gently from the plant (do not cut).
Stems are eaten but the leaf is poisonous

Spinach *Spinacia oleracea* Chenopodiaceae

Growing conditions

Prefers cool, shaded positions.

Best between 15 and 19 degrees C.

Nutrient requirements

Nitrogen is most important.
NPK ratio should be 10:4:12.
Sensitive to a lack of manganese, copper, molybdenum and iron.
pH 6.0 to 7.0

Suitable systems

Most aggregate media at 10 cm deep give excellent results.
NFT using Growpots or Vinidex channel.
Rockwool slabs have given excellent results.

Planting

Sow seed in sand or perlite and transplant into hydroponic system at 6 – 8 leaf stage.
Space plants 8 – 10 cm apart.

Problems

Chewing insects, slugs and snails can be a problem.

Sweet potato *Ipomoea* Convolvulaceae

Growing conditions

Must have warm dry air conditions and shade in very hot conditions.

Nutrient requirements

Average rate of nutrient uptake – neither heavy nor light.
Potassium, phosphorus, calcium and magnesium are needed in higher than normal ratios.
pH 5.5 to 6.0
EC of around 2.0 mS/cm (sensitive to levels over 2.5mS/cm).

Suitable systems

Sand culture is well suited according to Sholto Douglas.
Has been successful in perlite.
Sand or gravel in foam boxes fed with dripper have been successful.

Planting

Cuttings approximately 20 cm long are half inserted in media and strike easily (cuttings should be shaded until roots form).

Special cultural techniques

Trellising needed.

Problems

Several insect problems including moth grubs, beetles and weevils.
Fungal diseases which cause rot.

Harvest and post harvest

3 to 6 months after planting.

Taro *Calocasia esculenta* Araceae

Growing conditions

Grows most rapidly during the tropical monsoon season under wet, hot conditions.
Drainage and aeration must be good.

Nutrient requirements

Requires an acid root zone.

Suitable systems

Run to waste (i.e. open) aggregate systems with sand or gravel have proven best.
Sand or gravel are perhaps most suitable.

Planting

Plant young suckers taken from the base of established plants, or sections of tuber containing a piece of leaf stalk.
Space 30 cm apart and up to 1 m between rows.

Special cultural techniques

Push media up around base of plants as they grow, keeping tubers well covered.

Problems

Few.

Harvest and post harvest

Harvest 6 – 8 months after planting.
You should harvest around 8 kg per plant.

Varieties

The Dasheen varieties must always remain wet.
The Eddoes varieties tolerate extremes of dry and wet in the media.

Tomato *Lycopersicon esculentum* Solanaceae

Growing conditions

Requires 21 to 24 degrees C for optimum growth.
Growth slows significantly below 18 or above 27 degrees C.
Requires good aeration and drainage.
In very hot conditions some shading is needed.
Avoid very high humidity.

Nutrient requirements

Essential elements for proper growth and development in tomato production include oxygen, hydrogen, nitrogen, carbon, phosphorus, calcium, sulphur, magnesium, manganese, iron, copper, zinc, boron, and molybdenum. Any one of these elements may become a limiting factor in plant health.
Regular feeding is needed to avoid stunted growth and reduced cropping.
pH 6.0 to 6.5
Before planting, irrigate the media with nutrient solution to achieve an EC of 5.0 mS/cm. maintain this feed strength for about a month and then decrease it gradually to 3.0 mS/cm over the next 8 weeks, then to between 2.0 and 2.5 mS/cm over the summer.
The ratio of potassium to calcium should stay at 3:2 throughout the life of the crop (N.B. some sources suggest a K:Ca ratio of 2:1).
Calcium to magnesium ratio should be 4:1.
Shortage of calcium can lead to blossom end rot and can affect the size of the fruit. Calcium is usually applied as calcium nitrate in the range of 250 to 500 ppm.
Potassium to nitrogen ratio should be 1.4:1` early in the crop but increased to 1.8:1 providing higher potassium later in the crop. Potassium is essential for good fruit quality, and higher levels can increase the fruits shelf life. Potassium levels can vary from 50 to 400 ppm without affecting yields, but higher potassium levels improve fruit quality such as dry matter and electrical conductivity of the juice, which enhances flavour.
Some growers use different concentrations of nitrogen for winter and summer crops, since tomato plants' nitrogen requirements can vary significantly between winter and summer.
Phosphate should be relatively low, at about 40 ppm throughout the crop. High phosphorus levels (over 100 ppm) can result in iron deficiency

Sodium and chlorine levels should be kept as low as possible.
Trace elements are normally supplied in the following amounts, irrespective of the stage of growth:

NUTRIENT	PPM
Iron	1.00
Manganese	0.50
Zinc	0.40
Boron	0.30
Molybdenum	0.05
Copper	0.05

Iron is important in hydroponic tomato cultivation. Some sources recommend iron levels of up to 5 ppm. Iron is added in the form of iron sulphate or as chelates containing iron. The chelate form is often preferred since the iron remains in solution and is relatively available over a wide pH range. The most popular compound is EDTA, but use of this molecule may be restricted or prohibited in some countries because it does not break down in the environment, and has the potential to contaminate natural waters.
Iron deficiency in nutrient solutions is one of the most common problems in container production of tomatoes. Symptoms can develop slowly and growers need to be constantly observant.
Zinc levels are critical (below 0.25 ppm can cause deficiency and above 1 ppm can cause toxicity).

Suitable systems

NFT is the most commonly used method throughout the world.
Multi-level NFT has shown great potential for increased production (in Poland).
Under NFT systems the size of fruits decreases towards the bottom end of a channel (hence total production is decreased).
Aggregate culture – Sutherland reports excellent results in most aggregate culture at 15 cm depth. Growing tomatoes in pots is an easy and effective culture method and is widely used, both in the industry and by amateur growers. A variety of media have been used successfully including Perlite, rockwool, sand, and gravel. Some media are more effective than others and Perlite seems to be a good all round choice with many advantages – such as its reusability, its absorbency and its drainage capacity.
Rockwool is used commercially in the Netherlands and also has many advantages.

Planting

Germinate seed in rockwool propagating blocks, or in vermiculite or perlite seed raising mixes, and transplant into your system.

Special cultural techniques

Prune out side shoots until flowering commences.
Trellising is necessary.
Bees may need to be introduced for pollination in greenhouse crops. Other methods, such as mechanical vibration of plants, have also been used in greenhouse production to achieve optimum pollination.

Problems

Blossom end rot is encouraged by any stress on the plant. Such stresses include irregular growth rate, inadequate oxygen levels around the plant root zone (resulting from poor nutrient solution or from heating of nutrient solutions), disruptions to supply or balance of the nutrient solution, and inadequate plant uptake of calcium. It is worth noting that while calcium deficiencies are a direct cause of blossom end rot, a variety of factors (including the amount of dissolved oxygen and the temperature of the solution) can prevent tomato uptake of calcium from nutrient solutions, so addition of more calcium will not necessarily rectify the problem.
Birds will attack ripe fruits.
Pollination can be a problem in a greenhouse (wind and insects normally contribute towards pollination) various technologies have been utilised in greenhouse tomato production to overcome this pollination problem.
Don't smoke near tomatoes. A virus carried in tobacco can infect the plants.
Other pests include aphis, fruit fly, potato beetle, corn earworm, leafminer, white fly and mites.
Other diseases include anthracnose, bacterial canker, bacterial spot, blight, fusarium wilt, verticillium wilt and leaf mould.

Harvest and post harvest

Can be harvested green or firm and pink. Fruit should be handled with care to prevent bruising or skin breakage. Damage can still be done when fruit are green, although it may not become evident until fruit starts to ripen. The main mechanical damage encountered in commercial tomato crops is bruising or skin breakage from impact, vibration or compression.
Firm ripe tomatoes should be stored at 7 to 10 degrees C with 70 to 80% relative humidity and reasonable ventilation. Storage at temperatures above this will increase respiration rates of harvested fruit and decrease shelf life.

Turnip *Brassica rapa* –Rapifera group Cruciferae

Growing conditions

Cool conditions are essential for proper development.
Media must be well drained and have good aeration.
Avoid heavy gritty media.

Nutrient requirements

Phosphorus, potassium and iron are most important.
Iron uptake can be a problem sometimes.
Higher than average boron requirements.
pH 6.0 to 6.5.

Suitable systems

Perlite or vermiculite (or a mixture) are likely to give the best results.

Planting
Sow seed direct into perlite or vermiculite.

Problems

There are few problems in the edible root, though leaves are often attacked by insects.

Harvest and post harvest

2 to 3 months from planting to harvest.
Cut leaves and wash roots at harvest.

Water Chestnut *Eleocharis dulcis* Cyperaceae

Growing conditions

Chinese water chestnut grows as a semi-submerged plant and so is highly suitable for hydroponic production.

Nutrient requirements
Nutrient requirements may be fairly small. Some authorities suggest that water chestnuts can be fed with old nutrient solution from other crops.

Suitable systems

Aggregate – media such as perlite or vermiculite.

Planting

Small corms are planted in spring. Loose media is probably more appropriate for water chestnuts than rockwool.

Harvest and post harvest

Large corms are harvested after leaves die off in autumn. Corms will reach about 50 mm in diameter. Water Chestnuts are best used fresh but can also be canned and preserved in other ways. Commercial markets exist for both fresh and preserved produce. Asian markets are likely to have high quality standards.

Watermelon *Citrullus lanatus* Cucurbitaceae

Growing conditions

As for pumpkin, but higher temperatures.
Ideally temperatures between 21 and 30 degrees C.

Nutrient requirements

pH 5.8
As for pumpkin

Suitable systems

As for pumpkin.
Vigorous root systems can block pipes and beds.
Not considered commercially viable in hydroponics.

Planting

Seed direct into rockwool propagating blocks, perlite or vermiculite.

Problems

As for zucchini

Harvest and post harvest

Harvest when skin starts to become bumpy and undersurface starts to turn yellow.

Varieties

Smaller bush-type varieties are most suited to hydroponics.

turnips

zucchini seedlings

CHAPTER 13 : BERRY AND OTHER FRUIT CROPS

Babaco Carica pentagona Caricaceae

Also known as Highland or mountain Papaya which originated in the cool subtropical climate of Ecuador's highlands. Cultivation is similar to Papaya, however Babaco can withstand cooler conditions and has been commercially produced hydroponically in temperate climate greenhouses. Minimum temperature conditions for crop development are 12—18 degrees C. Reaches 2 metres in height at maturity with an average fruit size of 1—1.4Kg. Averages 40—50 fruit per plant over an 18 month growing period. Yields of 100 tons per hectare from 2 year old babaco plants in New Zealand have been recorded.

Banana *Musa acuminate* Musaceae

Growing conditions

Average temperatures are best between 27°C and 29°C.
Minimum temperature of 15°C and maximum of 35°C.
Temperatures below 10-15°C reduce fruit quality, and frost kills the plant.
Humidity should be high.
Root zone should always be moist.

Nutrient requirements

NPK ratio of 12:1:16 is recommended.
pH 5.5 to 6.5.

Suitable systems

Due to the size of the plants, hydroponic growing is generally only relevant under glass in cooler climates where bananas would not normally grow. Not generally considered a commercially viable crop. Perlite or scoria at 40 cm deep give good results. Hydroponic bananas have been grown successfully in Iceland.

Planting

Propagate bananas vegetatively by removing suckers which grow from the rhizome beside old plants. Only take suckers free of nematodes and bunchy top virus.

Problems

Fusarium wilt used to be a problem until wilt-resistant varieties were developed. Bunchy top virus is a major problem with bananas, and wind protection is essential.

Harvest and post harvest

Fruit takes around three months to mature from flowering. The first harvest is within a year of planting.

Varieties

Grow fusarium-resistant varieties such as Giant Cavendish, Valery and Robusta.

Blackcurrant *Ribes nigrum* Saxifragaceae

Growing conditions

Blackcurrants are deciduous shrubs which require winter chilling to initiate fruiting.

Nutrient requirements

A recommended NPK ratio of 10:1:6.
pH of 6.0.

Suitable systems

Aggregate culture is recommended. Though little information on hydroponic culture is available, being shallow-rooted they should adapt well, though commercial application is doubtful.

Planting

Bushes should be planted 1.5 -1.8 m x 1.2-1.5 m apart. Either one-year-old or two-year-old bushes can be planted. One-year-old bushes should be 45 cm high and have a minimum of two branches; two-year-old bushes should have 4-5 branches, each over 60 cm long. Immediately after planting, branches should be pruned back to 1-2 buds above the growing medium.

Special cultural techniques

Black currants produce fruit on the previous season's growth. Pruning should therefore encourage a supply of new growth each season. In the second season of growth, weak shoots and some of the older canes should be removed to allow room for new growth. A framework of 6-8 strongly-growing upright canes should be left. In subsequent years this procedure should be repeated; no basal canes should be allowed to grow for longer than three years.

Problems

There are few pest and disease problems. Poor temperature conditions are the most common cause of crop failure.

Harvest and post harvest

Fruit matures in mid-summer and is borne on the bushes for a four-week period. The berries should be left on the bush until 99% of the crop is ripe. Mature bushes should produce up to 3 kg of fruit.

Varieties

Varieties which perform well include White Bud, Boskeep Giant, Carters Black Champion, Dunnet's and Black Naples.

Blueberry *Vaccinium spp.* Ericaceae

Growing conditions

Roots must remain moist at all times.

Nutrient requirements

Blueberries require an acid pH level of around 4.0 to 5.0.

Suitable systems

Blueberries have been grown with moderate success in 50% sand and 50% peat mix. Commercial viability in hydroponics is doubtful.

Planting

Bushes should be planted at a spacing of 1.5 x 1.5 m.

Special cultural techniques

Pruning of the bush in the first three years should be limited to removal of dead and diseased wood. During this period, only the vegetative buds should be allowed to grow (rub off the plumper fruiting buds). After year 3, the bush will be large enough to permit shaping. In mid-winter, older wood should be cut back to 30-40 cm to stimulate new shoots. Some branches may need to be fully removed to prevent overcrowding.

Problems

Blueberries are relatively free of pest and disease problems. One possible problem is the occurrence of botrytis (grey mould) which can affect flowers and ripe berries in wet and humid conditions. Birds can be a problem if the plants are outdoors.

Harvest and post harvest

Berries are ready for harvest in mid-summer with the fruit being borne on the bush for a period of six weeks. Berries should be allowed to ripen on the bush.

blueberries

Brambleberries *Rubus occidentalis.* Rosaceae

(includes Bosenberry, Loganberry, Youngberry)

Growing conditions

The root zone must be well aerated but always moist. A cold period of dormancy is needed.

Nutrient requirements

A NPK ratio of 10:1:10 is suggested.

Suitable systems

Gravel, sand, perlite or rockwool should be successful. Brambleberries are not suitable for NFT as their vigorous root growth would block the channels. Commercial viability in hydroponics may be limited.

Planting

Plant in rows 1 to 2 metres apart (depending on the variety).

Special cultural techniques

Trellis support and wind protection is necessary. Prune annually in winter while dormant, retaining half of the first year canes and half of the second season canes. The two-year-old canes will produce fruit the following summer and should then be removed the next winter to make way for fruiting wood.

Problems

Some types need bees for cross pollination.

Harvest and post harvest

Pick continuously as berries ripen. Each plant should yield 1.5 to 2 kg per year.

Citrus - Various species. Rutaceae

Growing Conditions

From temperate to topical depending on type grown. Hydroponic citrus is produced with use of greenhouse technology/protected cropping and containerised production where soils and climates are otherwise unsuitable.

Nutrient requirements

pH should be around 5.8—6.0
N and Mg need particular attention. Foliar sprays of trace elements such as iron are beneficial in cooler climates. Potassium levels need to be maintained during the fruit production stages for good fruit quality.
NPK ratios are species dependant.

Suitable systems

Containers of free draining media with drip irrigation of nutrient solution. Suitable substrates include rice hull, coconut fibre and similar combinations, although a wide range of hydroponic media has proven successful.

Special cultural techniques

Often grown as grafted plants on dwarfing root stocks to minimise plant size at maturity and allow for protected cropping. Need regular pruning to maintain tree size, shape and productivity.

Problems

Need correct temperatures (species dependant) for good flowering, fruit set and fruit development. Lemons, oranges, mandarins, and grapefruit are more cold tolerant than tropical types such as limes and so can be produced more readily in temperate climates. Citrus requiring cooler conditions can be difficult to produce in tropical/ humid climates due to disease problems. Hydroponics citrus can be prone to mite and thrips infestations. Will not tolerate overwatering or saturated root zone conditions. Some varieties are prone to root rot pathogens.

Harvest and Post harvest

Need to be harvested at the correct stage of maturity for maximum storage life. Most citrus have a post harvest life of at least 2 weeks at room temperature conditions.

Cherries—*Prunus avium* Rosaceae

Sweet cherries can be grown hydroponically under protected cultivation or outdoors in large (at least 40 litre) growing containers, beds or bags on grafted, dwarfing root stock. Hydroponic production allows careful application of nutrients and water and has been largely used to prevent the problems of fruit splitting on valuable fruit crops destined for export markets such as Japan where high quality fruit receives premium prices. Cultivation is similar to other fruit crops such as grapes and passionfruit.

Grapes - *Vitis viniifera* Vitaceae

Growing conditions

Table grapes (mostly seedless) have long been produced hydroponically under greenhouse or protected cropping conditions to produce high quality bunches often with the use of plant growth regulators for fruit set. Hydroponic production allows for the production of high quality fruit destined for export markets such as Japan. Grapes require a period of chilling, although this can be provided artifically where fruit is to be produced out of season. Warm conditions (18—24º C) are required for bud break, flowering and fruit development with good light levels for sugar production and high Brix fruit. Some hydroponic production of wine grapes is being researched, particularly in areas where the soil is infected with various pests and diseases.

Nutrient requirements

Nitrogen levels need to maintained from the time of bud break through to fruit set. Minimal nutrition during the dormancy period. Potassium and calcium are important when the vines are under high fruit loading to maintain sugars, acidity and flavour compounds. Deficient irrigation or application of high EC will improve the soluble solids contents and hence flavour of the berries.

Suitable systems

Large growing containers for vines which may be cropped for over 10 years—minimum of 40 litres of free draining growing media.

Planting

Grapes are obtained as grafted plants, many with resistance to Phylloxera. Individual plants need a large amount of growing space and support at maturity. Young plants are often grown at a higher density and spaced out as the vines mature. Various methods of support are used with the most common being an overhead trellis system which allow the fruit to be harvested from underneath the vine.

Special cultural techniques

Grape vines need careful and heavy pruning for maximum fruit production and vine vigour. Leaf removal and fruit thinning may also be required for high quality table grape production.

Problems

Phylloxera beetle for vines without resistance. Common greenhouse pests and diseases such as mites, scale, whitefly, mealy bug and root rot diseases in unsterilised growing media and under over watered conditions. Lack of winter chill can reduce flowering and fruit set. Botrytis (grey mould) under humid conditions and of the fruit post harvest.

Harvest and post harvest

Brix levels should be checked as fruit approaches maturity to determine harvest date for maximum sweetness. Fruits require careful handling to prevent bruising and bursting. Store chilled and separate bunches with perforated plastic wraps.

Varieties

Many varieties of table and wine grape available. `Thompson seedless' is the most important variety of table grape grown in many countries (white variety). Black Beauty, and Cardinal (red) are other popular table varieties.

grapes

Passionfruit— *Passiflora edulis* Passifloraceae

Growing Conditions

Purple passionfruit are perennial vines that are semi woody at maturity. Vegetative vine growth will occur year round provided temperatures are within 16—28° C and don't drop below 12° C for any length of time. Passionfruit can be grown in temperate climates but produce little or no growth through the winter period. Greenhouse grown passionfruit in cooler climates can be forced to continually flower and fruit in flushes so that fruit can be harvested year round. Day length extension through winter with supplementary light will force vines into flowering under winter conditions.

Nutrient requirements

A nutrient formulation high in nitrogen can be used for young seedlings and plants up until the time of fruit set, when potassium levels need to be boosted. The acidic pulp of passionfruit contains high levels of potassium and this needs to be maintained for maximum fruit flavour. EC levels are recommended to be 1—1.5 for seedlings and 2—2.5 for fruiting vines. Fruiting formulations should contain at least 245 ppm of N, 269 ppm of K, 54 ppm of P, 48 ppm of Mg and 276 ppm of Ca. Recommended pH level is 5.9—6.0

Suitable systems

Large media filled containers (20—25 litres per plant) with substrates such as sawdust, composed pine bark, coconut fibre and similar media. Passionfruit has been successfully grown in rockwool slabs under greenhouse conditions in much the same way as long term tomato crops.

Planting

Most passionfruit crops are started from seed which germinates readily at 24—26° C, however grafted planted can also be used. Germination can take up to 6 weeks, but most seedlings appear within 3 weeks. Temperatures should be reduced to 20° C to harden off young plants before planting out. Light shading is beneficial under high light conditions.

Special culture techniques

Passionfruit grow into a large, sprawling vine at maturity and need support and heavy pruning. Passionfruit vines are typically trained to four leader shoots which are trained upwards. Strings can be tied around each shoot and strung to an overhead wire. Another option is to use a trellis type system. Pruning will be required in the second and third years of growth since vines only bear fruit on current seasons growth. Plants are usually replaced after 2—3 years production. Purple passion fruit also require pollination, usually by bees but are self compatible. Flowers can also be pollinated by hand.

Problems

Lack of sufficient pollination causes fruit to be lacking in seed numbers and pulp. Flowering can be inhibited by both low and high temperatures (above 30° C). Low light will reduce fruit set. Vines can suffer from Phytophthora root rot. Other disease problems include `Grease spot' (bacterial) and many types of fungal root rots. Whitefly, mealy bug, green vegetable bug, aphids, mites and caterpillars are all common pest of passionfruit. Passionvine hopper is widespread in Australia and New Zealand and is the major pest of passionfruit crops.

Harvest and post harvest

Hydroponic passionfruit achieve yields of 20 tons per hectare at maturity. Mature fruit are either harvested from the ground beneath the vines once or twice a day or cut from the vine which reduces skin damage and bruising. Fruit harvested from the vine must be fully coloured and close to natural fruit drop. Fruit is often washed and high quality fruit will have the calyx removed and stalk cut back to prevent damage to other fruit during shipment.

Varieties

Purple Gold and E-23 are common purple types, although many others exist which may perform well in hydroponics.

PawPaw *Carica papaya* Caricaceae

Growing conditions

Ideal temperatures are between 21°C and 27°C. Requires full sun and no frost. Good aeration and drainage are important.

Nutrient requirements

pH should be around 6.5.
NPK recommended at 7:1:18.

Suitable systems

Sholto Douglas reports excellent results in a greenhouse. Aggregate culture would be the system most likely to succeed.

Planting

Pawpaw are normally propagated by seed. Plants can be any one of three sex types:
1. Male only.
2. Female only.
3. Bearing flowers with both male and female parts.
The male flower plants do not bear fruit at all. These plants are discarded as soon as the sex is determined. Each plant requires a minimum of 3 square metres.

Special cultural techniques

Trellis and wind protection are essential.

Problems

Plants become too tall to be managed within a few years. When this happens, they need to be removed and replaced. Mites can be a serious problem, although regular spraying will alleviate this problem. Fruit flies can be a significant pest. Fungal and viral diseases can also be a problem.

Harvest and post harvest

Trees can bear fruit within the first year and crop continuously, providing growing conditions are maintained.

Pepino *Solanum muricatum* Solanaceae

A small bush to 1 m tall and 1 m diameter, related to the tomato and producing a small oval fruit similar in taste to some melons.

Growing conditions

Pepinos like a similar root environment to tomatoes. They are a little more cold hardy than tomatoes, but can be killed by frost. Pepinos will grow in semi shade.

Nutrient requirements

Pepinos require oxygen, hydrogen, nitrogen, carbon, phosphorus, calcium, sulphur, magnesium, manganese, iron, copper, zinc, boron, and molybdenum. Any one of these elements may become a limiting factor in plant health. Regular feeding is needed to avoid stunted growth and reduced cropping. They prefer a pH of 6.0 to 6.5. Before planting, irrigate the media with nutrient solution to achieve an EC of 5.0 mS/cm. maintain this feed strength for about a month and then decrease it gradually to 3.0 mS/cm over the next 8 weeks, then to between 2.0 and 2.5 mS/cm over the summer.

The ratio of potassium to calcium should stay at 3:2 throughout the life of the crop (N.B. some sources suggest a K:Ca ratio of 2:1).

The calcium to magnesium ratio should be 4:1. Shortage of calcium can lead to blossom end rot and can affect the size of the fruit. Calcium is usually applied as calcium nitrate in the range of 250 to 500 ppm. The potassium to nitrogen ratio should be 1.4:1 early in the crop but increased to 1.8:1 providing higher potassium later in the crop. Potassium is essential for good fruit quality, and higher levels can increase the fruits shelf life. Potassium levels can vary from 50 to 400 ppm without affecting yields, but higher potassium levels improve fruit quality.

Phosphate should be relatively low, at about 40 ppm throughout the crop. High phosphorus levels (over 100 ppm) can result in iron deficiency. Sodium and chlorine levels should be kept as low as possible. Trace elements are normally supplied in the following amounts, irrespective of the stage of growth:

NUTRIENT	PPM
Iron	1.00
Manganese	0.50
Zinc	0.40
Boron	0.30
Molybdenum	0.05
Copper	0.05

Iron is important. Some sources recommend iron levels of up to 5 ppm. Iron is added in the form of iron sulphate or as chelates containing iron. The chelate form is often preferred since the iron remains in solution and is relatively available over a wide pH range. The most popular compound is EDTA, but use of this molecule may be restricted or prohibited in some countries because it does not break down in the environment, and has the potential to contaminate natural waters. Zinc levels are critical (below 0.25 ppm can cause deficiency and above 1 ppm can cause toxicity).

Suitable systems

Pepinos have been grown successfully in gravel and sand culture. This fruit may have some commercial potential, although as yet it has not seriously been tested in hydroponics.

Planting

Plant pepinos at 0.5 to 0.8 metre intervals. They grow readily from cuttings or natural layers.

Special cultural techniques

Trellis is essential. Stems must be tied up or they will sprout roots wherever they come in contact with moist media. This self-layering leads to a reduction in fruit production.

Problems

Avoid severe cold or heat.
White fly and various other pests and diseases that affect tomatoes can occur.

Harvest and post harvest

Harvest pepinos when the fruit turns yellow. They keep well in cool conditions, although cold temperatures can damage fruit.

Pineapple *Ananas comosus* Bromeliaceae

Growing conditions

Day temperatures are best not exceeding 31°C. Once fruits begin to mature, night temperatures should not drop below 21°C. Dry air environment, and moist, well-drained, well-aerated root environment. It will survive reduced watering but fruit production decreases.

Nutrient requirements

pH 5.5 to 6.0. High levels of nitrogen and potassium are important early in the crop.
Iron and zinc are particularly important minor nutrients.

Suitable systems

Sholto Douglas reports good results growing pineapples in hydroponics. Aggregate culture is most likely to succeed.

Planting

Plant pineapple crowns (i.e. the leafy top cut directly from the fruit) directly into sand/perlite or vermiculite/perlite, in a permanent position.

Special cultural techniques

After harvest, side shoots or suckers develop which produce a second crop about a year later. This second crop is not as good as the first. Remove and replant after the second crop.

Problems

Mealy bug can cause problems when growing pineapples. Several fungal problems may arise, including rots caused by Phytophthora species.

Harvest and post harvest

The first harvest is up to two years after planting.

Raspberry (Red) *Rubus idaeus* Rosaceae

Raspberries are well suited to hydroponic greenhouse production as cane height can be controlled and there are a number of cultivars that produce early and late season crops. Out of season production is also possible making this a high value crop for many areas.

Growing Conditions

Pre chilled canes planted out in a greenhouse need temperatures in the range 10—12° C for the first 2 weeks, thereafter raised to a minimum of 12° C up to 24° C. Temperatures above 30° C cause growth and fruiting problems. Air movement is essential to eliminate areas of high humidity that cause fungal infection of canes and fruit. Good light levels or supplementary lighting are required for the production of out of season fruit in winter in many areas.

Nutrient requirements

Raspberries need high level of potassium (K) to maintain fruit quality and flavour and sufficient calcium (Ca) to assist with firmness and maintaining a long shelf life. pH levels in the range 5.8—6.0 are advised.

Suitable systems

Both media and NFT systems can be used for raspberries. Media grown plants need a free draining substrate such as sand, pear, perlite or vermiculite. Container grown plants need a minimum of 20 litres for second year floricane types. First year primocane types can be grown in 6 litre containers. NFT grown plants need to have a wide diameter channel and solution warming can be used for winter production.

Special culture techniques

Systems of production vary. Dormant canes can be selected from field grown crops for lifting with some root structure intact. The canes must be strong and 1—1.5 m in length with a number of buds. Dormant raspberry canes need a good reserve of carbohydrates to support the first flush of new growth when planted into the greenhouse. Dormant canes need to be wrapped in plastic and placed in cold storage at 4°C for 6 weeks. After this time canes can be transplanted into a warm greenhouse and hydroponic system for crop production. Once the canopy has developed to a sufficient size the canes are tipped so that fruit development is favoured. There are 2 main types of raspberry plant—those that fruit on first year shoots called `primocane varieties' and those which fruit on second year wood, termed `floricane' types. Floricane types produce fruit in early summer, but can be manipulated to fruit in winter under protected cultivation and are more suited to hydroponic production.

Flowering will begin on canes around 6—8 weeks from planting out from cold storage. Flowers require good pollination for fruit set, size and shape. Bumble bees are often introduced into greenhouses for this purpose. Raspberry plants can pollinate without the presence of pollinators in the greenhouse, but this reduces the number of fruit and can affect fruit shape.

Problems

It is important to select raspberry stock from plants certified to be free of viruses, pests and diseases. Rust and Botrytis are the main diseases of greenhouse raspberries, along with Phytophthora root rot under waterlogged conditions. Pests include the raspberry aphid, which can spread raspberry viruses diseases, as well as thrips, mites and whitefly. Incorrect temperatures or lack of chilling will result in bud break failure, lack of flowers and low yields. Lack of pollination will result in smaller berries, berry drop and fruits than crumble after harvest.

Harvest and post harvest

Hydroponic yields of 4 times the average of soil grown crops have been reported with the percentage of unmarketable berries being considerably lower. Fruit is hand harvested to reduce damage and bruising and packaged into small (200 g) punnets, individually wrapped and labelled for shipment. Storage is under refrigeration at 2—4° C, although shelf life is limited to 6—8 days in most cases.

Varieties

Varieties vary depending on what planting stock is available locally from outdoor plantings.

Redcurrant *Ribes sativum* Rosaceae

As for blackcurrant.

Strawberry *Fragaria ananassa* Rosaceae

Strawberries are very well suited to hydroponic growing and they offer a quick return on capital outlays for the grower.

Growing conditions

Strawberries require good drainage and aeration. They need reasonable ventilation (air movement) around foliage and fruit. A good quality water supply (with a low level of dissolved salts) is critical.

In summer, plantings require approximately 20 litres of water per square metre for good vegetative growth in sand culture. The Ideal temperature for good vegetative growth is 15°C to 18°C. Low temperatures over winter are required to break the dormancy which develops in autumn and higher temperatures are required for good crop development.

Nutrient requirements

Strawberries require a pH of 6.0 (a high pH will cause iron deficiency). Sulphur, boron and magnesium are important minor nutrients. A lack of boron can result in poor pollination. Potassium or magnesium deficiencies can cause leaf burn. Potassium deficiency may also cause insipid and soft fruit. Keep the level of chlorine present to a minimum. Phosphorus level should be higher

than in that used in the average nutrient mix.

Suitable systems

Many commercial strawberry hydroponic systems are based on a trough system. Troughs, filled with gravel, perlite or granulated rockwool, are typically 10-15 cm x 15-20cm, with four or five troughs mounted vertically.

Strawberries can also be produced using the hanging bag system. In this system, a bag made of black irrigation fluming is hung from a frame. The "bag" is usually 900-1200mm long and 150mm in diameter. It is filled with a growth medium, and nutrients are fed in at the top and run to waste at the bottom. The strawberries are planted in holes in the side of the bag. Whilst this is an inexpensive system to set up, many growers do not fully understand the technique and fail to produce good crops.

Planting

Plants are spaced at 35-40 cm intervals.

Runners are removed from parent plants in mid to late summer and stored between 0°C and -2°C until ready for planting. Only use material which is free of virus. New varieties are propagated in tissue culture.

Put in any new plants in early autumn. Trim the roots to around 8 cm when planting. Runners which have been established in pots may also be used as planting material. Any flowers with runners are removed at planting time to prevent premature fruit formation.

Early plantings (late autumn) can give up to double the crop in their first season compared with late plantings (late winter).

Special cultural techniques

Remove runners which develop on plants as they will detract from the quantity and quality of the crop (ie. only retain the main plant). Cut old leaves off at the end of each season's harvest (late autumn), leaving only emerging new foliage.

Replant every three to four years, (after that time, virus disease is highly likely to be affecting production, even if plants still look healthy).
Some types of granulated media (eg. perlite and vermiculite) will adhere to the fruit. Laying a plastic mulch on the surface of such media will keep the fruit clean.

Problems

Viruses transmitted by aphis are a major problem.
Snails, slugs, birds and various grubs will attack fruit at times.
Fungal diseases such as botrytis can also affect fruit, particularly under humid conditions.

Harvest and post harvest

Harvest fruit as it changes to red on a daily basis. Strawberries are ready to pick when the colour has changed 60-70% pink, and the rest of the fruit is still white. Pick the fruit with the stalk still attached and place immediately in a cool place (10-15°C). Strawberries harvested at this stage and stored at 2°C will keep for up to 10 days.
Flavour is best on berries harvested when fully red, but the storage period is greatly reduced.

Vanilla—*Vanilla Planifolia* Orchidaceae

Vanilla is a relatively new hydroponic crop being produced in greenhouses in climates such as Hawaii. Vanilla is an orchid with long, trailing stems which need support as they climb upwards reaching a length in excess of 10 meters. Stems are often tied to wooden stakes to replicate their natural habit of climbing trees. Access to the upper stems is required for hand pollination of the flowers which is necessary for bean pod production. Flowers only open briefly and must be pollinated within a day by hand which creates a large labour requirement for this crop. Plants are grown in beds of free draining, coarse media such as volcanic pumice or scoria mixed with fibrous material such as coco peat. Nutrient solution is drip irrigated as required to support the rapid growth rate of the plant under tropical or sub tropical conditions. Protected cultivation produces higher yields and good quality pods which are harvested before they are fully ripe and cured to develop their aroma and flavour.

strawberries

CHAPTER 14 : FLOWER CROPS

Alstroemeria (Peruvian Lily) Alstroemeriaceae

Growing conditions

Requires good drainage and constant moisture.
Four weeks or more at 5°C or lower is required over winter to initiate flower buds.
As day length increases, flowering starts and continues while temperatures remain below 18°C.

Nutrient requirements

Suggested NPK ratio 15:1:9.
Only apply nitrogen in nitrate form.

Suitable systems

Recommended for sand or perlite culture in beds, foam boxes or plastic bags.

Planting

Propagated by division of rhizomes.

Special cultural techniques

Grow through a horizontal trellis.

Problems

Relatively free of pests and diseases.
White fly, caterpillars and aphis can occur under warm conditions.
Regular applications of fungicide and insecticide are used when grown commercially under glass.

Harvest and post harvest

Harvest by pulling off stems (this stimulates further flowering).
Harvest when first flowers are opening and strip lower leaves from stem before placing in water in a cool position.

Amaryllis (Hippeastrum) Amaryllidaceae

Amaryllis is grown commercially both as a cut flower and for bulb production.

Growing conditions

Minimum root temperature of 20°C.
High humidity is preferable.
Root zone must have constant moisture but be reasonably well aerated.
Night air temperature should not drop below 18°C.
Carbon dioxide enrichment has been used in some greenhouses in Europe to maximise growth.

Nutrient requirements

Nutrient requirement is low in early stages but should be increased as the crop develops.

Suitable systems

Aggregate culture is probably most appropriate.
Sand and sand/perlite have been used most successfully.

Planting

Propagate from offsets or scale cuttings.
Plant out in beds mid to late winter. Spacing will relate to the size of the bulbs being planted.

Special cultural techniques

Ventilation can be important, but shading is only ever used in extreme situations.
Horizontal mesh trellis is important, among other reasons, to control fungal diseases by improving air movement around the plant.

Problems

Pests include mites, thrip and aphis.
Several fungal diseases including fusarium, as well as virus, can occur.

Harvest and post harvest

Lift bulbs late autumn and dry quickly at 23°C before marketing or storing for replanting.
Harvest flowers when buds become loose, but before they open.
Store at 7-10°C.

amaryllis

Anigozanthus (Kangaroo Paw) Haemodoraceae

Kangaroo Paw is a popular cut flower. Perhaps the greatest limiting factor is ink spot fungal disease, which is difficult to control in most soil plantings. Hydroponic culture may offer a way of overcoming this disease.

Growing conditions

Needs a well-drained and aerated root zone.
Requires low humidity.
Optimum day temperatures are between 18 and 27°C.
Requires a sunny position.
There is considerable variation in specific climatic preferences between varieties.

Nutrient requirements

Unknown in detail.
Iron is important, phosphorus should not be too high.

Suitable systems

Gravel, sand or rockwool are suggested.

Planting

Propagate by division or tissue culture. Seedlings are variable.
Spacing depends on variety.

Problems

Main problem is ink spot fungal disease which is very difficult to control.

Harvest and post harvest

Harvest continually over warm months when first flowers open on a stem.

Varieties

A range of hybrid varieties under the name 'Bush Gems' is relatively resistant to ink spot.

Antirrhinum (Snapdragon) Scrophulariaceae

Growing conditions

Cool greenhouse crop, a perennial usually treated as an annual, providing cut flowers mainly in winter and spring.
For winter-flowering varieties, temperatures in the range of 10°C (night) to 16°C (day) are best. For spring varieties, 16-22°C, and for summer types 18-24°C.
For the first 4-6 weeks of growth all types respond well to a night temperature of 16°C.

Nutrient requirements

Requires high calcium.
pH 6.5
Sensitive to high EC levels.

Suitable systems

Gravel and sand culture have been very successful.
Modified NFT (with coarse sand in the channels) should succeed.
Rockwool should succeed.

Planting

Sow seed in a container of san, or peat and sand and transplant when small (approximately one month after sowing) with a ball of medium around the roots to their permanent position, with a spacing of around 20 cm x 20 cm.

Special cultural techniques

Pinch growing tip out at 6-8 cm to encourage branching.

Problems

Seed is very fine so sub-irrigation is best for watering at this stage.

Harvest and post harvest

Flowers are cut when the bottom florets are completely expanded, while the tip florets are in tight bud.
The cut stems should be put immediately into water and ideally stored at an air temperature of 4°C.

anigozanthus

Aster Asteraceae

Growing conditions

An annual producing flowers in summer and autumn.
Some shade in hot weather is beneficial.
Night temperatures above 23°C result in weaker stems and smaller flower heads.
Constant rate of growth is important to achieve good crops.
Avoid rapid temperature changes.

Nutrient requirements

Heavy feeders.
Require high levels of calcium.
pH 6.0 to 6.5.

Suitable systems

Few references available specific to hydroponic growing.
We suggest rockwool and gravel culture would be appropriate.

Planting

Grown from seed then transplanted when small either bare-rooted or with ball of germination medium around roots.
Spacing depends on variety, but generally around 20 cm x 20 cm.
Optimum germination temperature is 21°C.

Special cultural techniques

Each shoot from the main stem is disbudded to a single flower.
Remove any suckers which develop.
Grow through one or two layers of horizontal trellis (15 cm mesh).
Artificial lighting is sometimes used to extend day length and stimulate flowering.

Problems

Pests include slugs, snails, aphis.
Diseases include anthracnose, botrytis, fusarium and verticillium wilt, powdery and downy mildew, and viral diseases.
A regular spray program is necessary, particularly to control aphis and botrytis. Be careful to follow spray recommendations as aster foliage is susceptible to chemical spray burn.

Harvest and post harvest

Cut when outside petals are fully open but some inside petals are still folded and retain a slight tinge of green.
Strip leaves from bottom one-third of stem, bunch and stand in water, ideally in a cool room at 5-8°C.

Begonia Begoniaceae

Growing conditions

Does not tolerate intense light conditions.
Requires shading in warm or mild climates.
Air temperature is best between 21°C and 27°C.
The root environment should be more moist than average, but well drained. (At lower temperatures, root environment needs to be drier.)
While some types will survive at tow temperatures, all are frost tender.

Nutrient requirements

Has low iron, high potassium requirements.
pH 6.5

Suitable systems

Capillary-fed aggregate systems are excellent.
Has been grown very successfully in perlite and 50/50 perlite and sand.

Planting

Propagate by seed, leaf or stem cuttings.

Problems

Pests include aphis, scale, mealy bug.
Diseases include botrytis, anthracnose, various root rot fungi, verticillium wilt, powdery mildew, bacterial spot and crown gall.

Harvest and post harvest

Several types grown and sold as container plants, notably tuberous begonias in full bloom.

Canna Cannaceae

Growing conditions

Requires good drainage and aeration.
Requires frequent irrigations and ample nutrient to maintain a fast growth rate.

Nutrient requirements

Heavy feeders but nitrogen should be minimised to prevent vegetative growth at the expense of flowers.
pH 6.0

Suitable systems

Has been successful in aggregate culture.
Commercial application of cannas in hydroponics is doubtful.

Planting

Propagated by root division.

Special cultural techniques

Trellis and wind protection are needed.

Problems

Very few major problems.

canna

Carnation *Dianthus sp.* Caryophyllaceae

Growing conditions

Good aeration and drainage are critical for optimum cropping.
Optimum temperature for disbuds (or Sims) is 15-18°C, and preferably not over 22°C.
Optimum temperature for spray (bunching) carnations is up to 6°C higher in summer and 3°C higher in winter.
Will tolerate almost any freezing temperatures.
Flowering is initiated by both mild to warm temperature and medium to long days. You need both a good day length and adequate temperatures.
Water requirement can be up to eight times as much in mid-summer compared to mid-winter.
Avoid high humidity.

Nutrient requirements

EC should never exceed 3.5 mS/cm; ideally keep at 2.0 mS/cm.
pH should be around 6.0.
Nutrient solution should be approximately as follows:

NUTRIENT	PPM
Nitrogen	170
Iron	1.2
Phosphorus	50
Manganese	0.4
Potassium	245
Copper	0.4
Calcium	160
Zinc	0.2
Magnesium	25
Boron	0.2
Molybdenum	0.05

Sulphur should not exceed 32 ppm.
Nitrogen should be supplied as nitrate, not as an ammonium salt.
While plants are becoming established, nitrogen and calcium requirements are high, but during flowering calcium requirement decreases. Up to 30 kg/1000 litre of additional calcium nitrate may be added to the standard nutrient over the first few months and gradually be reduced as the plants establish. Established plants should be fed with the standard solution.

Suitable systems

Rockwool has been used commercially in the Netherlands since 1978.
Rockwool slabs between 10 and 12 cm deep are more successful than shallower slabs. Six to eight drippers should be supplied per square metre of rockwool slab. Set slabs on plastic sheet base with a slight slope for sub-drainage. Plastic sheet can lead to reduced

humidity in a greenhouse – in some instances this needs to be countered with routine overhead misting.
Perlite 8-10 cm deep gives excellent results.
Scoria has given good results.

Planting

Use virus-tested cuttings from approved carnation growers. These may be supplied in Growool blocks or perlite tubes. (If in soil-based medium this must be washed off before planting.)
Disbudded carnations (eg. Sims) are planted at 30-36 plants per square metre.
Spray carnations are commonly planted at 36-48 plants per square metre. A wider spacing improves ventilation and reduces likelihood of disease.
Cropping starts around three months after planting.

Special cultural techniques

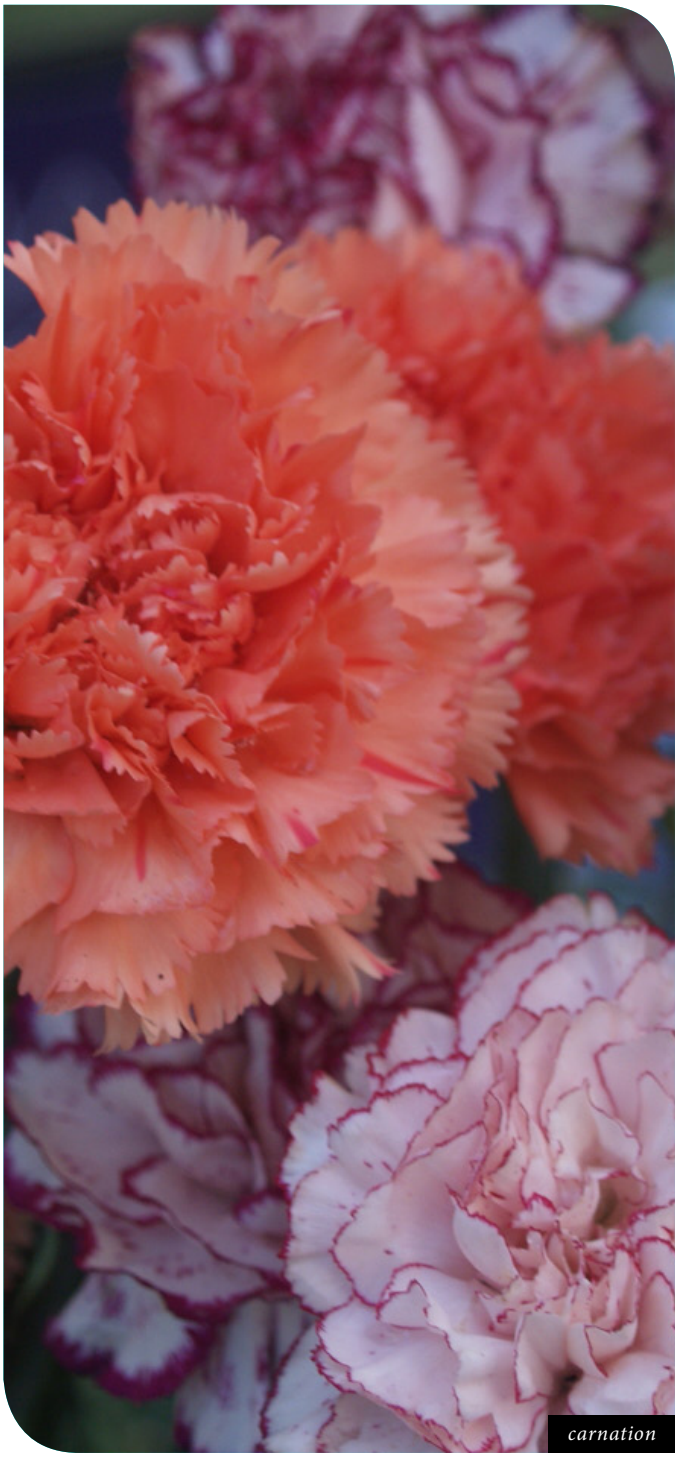
Open horizontal mesh 15-20 cm above the medium provides a support system.
Pruning is necessary to stop spindly undesirable growth habits. Pinch out the growing tip on young plants when they reach about 15 cm tall.
Artificial lighting is sometimes used to concentrate the flowering period (ie. you get more flower over a shorter period, but after that flowering is delayed until the next crop). This is done by lighting at 110 lux from dust till dawn for four weeks, usually in mid-winter.

Problems

Hygiene is very important for disease control and consequently crop quality.
Fusarium wilt (Fusarium oxysporum) spreads rapidly through irrigation.
Botrytis is sometimes a problem.
Alternaria leaf spot occurs as small purple spots which grow to larger black areas bearing spores.
Viral diseases, mainly transmitted by aphids, are a particularly serious problem, reducing cropping in many parts of the world. It is critical to plant only virus-free plants, and to control aphis to prevent healthy plants from becoming infected.
Do not get flower buds or petals wet as this can cause marking.
Flowers which develop at lower temperatures have a tendency to split.
Flowers developing at higher temperatures develop faster and tend to have weaker stems.
Aphis and mites can be very serious pests. Aphis spread virus and cause distorted growth. Mites cause mottling of the leaves and eventually drying of the foliage.
Thrip and caterpillars can also become a problem.

Harvest and post harvest

For single-flowering varieties the flowers are harvested when the bud has opened fully so that the outer petals are at right angles to the stem and the inner petals are still tightly bunched.
For spray types harvesting occurs when the top three flowers begin expanding and the lower buds are showing colour.
One part boric acid in ten parts water will improve the keeping quality of the flowers by up to one week.
Dipping treatments, based on sodium thiosulphate, that extend the keeping quality of the flowers are also available.
Harvested flowers can be damaged by ethylene. An ethylene-inhibiting chemical is used on flowers which are not sold as soon as they are picked.


carnation

Chrysanthemum Asteraceae

Growing conditions

Requires very good drainage, good aeration and constant moisture in the root zone.
Plants are frost tender.
Needs good light, though shading is sometimes used over summer to provide protection from extreme heat.
Buds do not form if the period of uninterrupted darkness exceeds 7 hours.

Nutrient requirements

Heavy feeders.
High nitrogen is important in the early stages.
Adequate phosphorus is critical at all stages.
Iron deficiency is more likely in poorly-aerated root zones.
If roots are too wet, high levels of potassium, sodium or nitrogen in the ammonium form will impair the uptake of magnesium, calcium and sulphur.
pH ideally 6.0 to 6.2.

Suitable systems

Aggregate culture has been very successful in sand or perlite.

Planting

Start cuttings in sand, vermiculite or rockwool propagating blocks.
Spacing is dependent on variety, with larger varieties spaced up to 70 cm apart.

Special cultural techniques

Pinch out growing tips to cause lateral growths.

Problems

Pests include aphis, mites, whitefly, leaf miners and caterpillars.

Diseases include verticillium wilt, sclerotinia wilt, septoria leaf spot, powdery mildew, botrytis and virus.

Harvest and post harvest

Flowers are harvested when the outer petals have opened, but the inner ones are still expanding.
Sprays are harvested when three or more flowers reach this stage.
The base of the flower stems should be dipped in boiling water for 30 seconds, then placed in buckets of water containing disinfectant such as sodium or calcium hypochlorite.
Flowers protected by a pre-harvest fungicide treatment can be cool stored for up to two weeks at 2-3°C as long as the flowers are dry and the stems are kept in water.

Dahlia Asteraceae

Growing conditions

Requires better than average moisture when growing fast, with good aeration and drainage.
Plants are frost sensitive.
Optimum temperature range is 16-19°C.

Nutrient requirements

Potassium and phosphorus important.
pH 6.0 to 7.0.

Suitable systems

Aggregate culture.

Planting

Propagate by cuttings or division.

Special cultural techniques

Trellising and wind protection are needed.

Problems

Mildew is more common in hydroponics than soil (plants being more susceptible when growth is very rapid).

Harvest and post harvest

Pick as buds just begin to burst open.

Freesia Iridaceae

Growing conditions

Corms require 16°C day temperatures (or higher) to commence growing. Once six leaves have formed flowers will begin to develop, and at this stage ideal temperature is 13°C – over 18°C flowering is reduced. After this point, temperatures between 12°C and 20°C give optimum growth.

Nutrient requirements

1.0 mS/cm for the first two months then increasing to 2.0 mS/cm.
pH 6.5.

Suitable systems

Rockwool has been successful in Europe.
Aggregate culture in beds should be successful.

Planting

Plant corms in autumn for spring flowering.

Special cultural techniques

A horizontal trellis for support is necessary.

Problems

Diseases include fusarium wilt, botrytis and virus.

Aphis is perhaps the most serious pest problem because it spreads viral disease.

Harvest and post harvest

Cut flowers when first bud is starting to open.
Harvesting starts within 10 to 12 weeks of planting.
Bunch and store at 2-4°C.

Gerbera Asteraceae

Growing conditions

Root aeration is extremely critical.

It is important to maintain active growth over winter to achieve good cropping in the second year.
At temperatures over 18°C the plants are evergreen, but below 18°C they die back to a dormant root system.
Commercially they are cropped in heated greenhouses.
They have a high light requirement.

Nutrient requirements

Maintain young plants on an EC of 2.0 mS/cm and gradually increase to 2.5 mS/cm as plants establish.
pH between 5.0 and 6.5.
pH can drop when plants are producing heavily – if this happens, flush the slab to remove any salt build-up and correct the pH.
pH tends to rise in early spring when there is a lot of leaf growth.
Nutrient solution as follows:

NUTRIENT	PPM
Nitrogen (as nitrate)	180
Iron	2
Boron	0.33
Phosphorus	46
Manganese	0.28
Potassium	255
Zinc	0.26
Calcium	160
Copper	0.05
Magnesium	24
Molybdenum	0.05

Sulphur should be no higher than 40.

Suitable systems

Growool slabs are used commercially in Europe.
Aggregate culture should also be commercially viable.

Planting

Plants are grown for two seasons then discarded.
Propagate by division.
Space 25-30 cm between plants.

Special cultural techniques

Horizontal trellis is needed.
Remove one leaf each time you move a flower to maintain balance between flower and leaf growth. At the end of winter remove all dead or damaged leaves and flower stems.

Problems

A sunny period followed by dull humid weather in summer can cause water problems with the plants losing water at an excessively high rate and requiring extra irrigations, both day and night.
Pest problems include caterpillars, mites, leaf hoppers, mealy bug and other insects.
Disease problems include botrytis, powdery mildew and some blight and rot-causing fungi.

Harvest and post harvest

Flowers must be reasonably mature with stamens in the second ring of disc flowers visible before picking. Pull off flower stalks rather than cutting. Put in a bucket of warm nutrient solution immediately they are picked.

Varieties

Different varieties have different water requirements.

Gladiolus Iridaceae

Growing conditions

Gladioli grow from a corm. Leaves and roots emerge from the corm in late winter or spring and develop into a plant. The old corm is totally absorbed by the growth, but a new corm forms with many smaller cormlets attached to its bottom. At the end of the growing season, the leaves and roots die back, leaving only the corm and cormlets alive. The corm and cormlets will not regrow until they have undergone a period of dormancy. Over this period, they are susceptible to rooting and hence need to be stored dry. Either remove dormant corms from a hydroponic system or leave the system dry for a period before attempting to start growing a new crop.
Corms formed when the root zone temperature are above 15°C are more dormant than those that mature when temperatures are cooler. Dormancy has been broken by storage at 5°C for two months followed by storage at 20°C.
Adequate light is needed to produce flowers. If light intensity is too low or day lengths too short, flowers will not occur.
Aeration is not as critical as with some crops, though good drainage is essential, particularly for early or late crops.
High humidity around the developing spike can cause fungal diseases and damaged flowers, though this risk is minimal as the flowers are generally picked before opening.
Drier conditions can increase the likelihood of foliage insect problems.
Drier conditions cause earlier flowering.

Nutrient requirements

The most common nutrient deficiencies are iron, boron and copper.
Iron deficiency is indicated by loss of colour between the leaf veins.
Boron deficiency may be indicated by leaves cracking horizontally .
Copper deficiency may be indicated by leaves wilting for no apparent reason.
Nitrogen supplied in the ammonium form increases susceptibility to the fungus *Botrytis gladiolorum*.
Nutrient solutions should preferably supply nitrogen in the nitrate form.
Potash and phosphorus are important.
Because the flower and new corm commence development only three to four weeks after planting, it is important to provide a strong supply of nutrients early in the growth cycle.

pH should be maintained between 5.5 and 6.5.

Suitable systems

Rockwool and NFT are not suitable for gladioli.
Aggregate culture is the most suitable technique as it is the only system which provides an appropriate depth and allows corms to be lifted easily for dormant storage at the end of each growing season.

Planting

Plant at a depth of 10 cm.

Special cultural techniques

Some form of trellising is required (either a horizontal mesh, or wires around a row at about 30 cm height).

Problems

Wet, cold conditions promote several diseases including stromatinia, botrytis and septoria.
In warm conditions gladioli are susceptible to the fungus *Fusarium oxysporum* which attack both the foliage and the corm.
Viral diseases spread by aphis are one of the most serious disease problems.
Viral infection is indicated by discolouration or blotching of foliage or flowers. Infected plants cannot be cured and must be removed and burnt to prevent further spread of the disease.
Thrips can be a serious problem in warm weather (above 20°C), causing silvery streaks on the foliage and subsequent decline in the plant.
Mites, caterpillars and a number of other insects can also be a problem.

Harvest and post harvest

Usually pick between 70 and 140 days from planting.
Harvest when the bottom two to four flowers on a stem are showing colour. Place in water as soon as picked and store in a cool room between 5°C and 7°C.

gladiolus

Gypsophila Caryophyllaceae

Growing conditions

Can be grown outdoors but needs shelter from hot, dry wind and rain during flowering.
Needs good light for flowering.
Requires good drainage.

Nutrient requirements

pH 6.0 – 7.5.
EC is maintained at 2 mS/cm in winter and 1.6 mS/cm in summer.

Suitable systems

Rockwool is used successfully for commercial production.

Planting

The perennial *Gypsophila paniculata* is cropped for two to three years.
Propagated by tissue culture or tip cuttings.

Cuttings should be taken before flower initiation occurs, at the 6-8 leaf stage. Cuttings are difficult to strike when taken from stock growing in cool, low light conditions.

Special cultural techniques

Remove the main central lateral to promote uniform growth on remaining shoots. Pinch the shoot at the fifth to seventh node.
Supplementary lighting and heating are needed for year-round production.
A trellis is needed to support the stems.

Problems

Flowering stops when daylength and temperatures decrease, at which time the crowns rosette.

Harvest

Harvest when 50% of the flowers on a stem are open.
Store in a high humidity cool room.

Varieties

Gypsophila paniculata 'Bristol Fairy' is the most commonly grown commercial variety.
Newer cultivars are 'Bridal Veil' and the Danziger cultivars from Israel.

Iris *Iridaceae*

Growing conditions

In high humidity, plant rhizomes or bulbs close to the surface of the media. In hot dry air conditions, plant deeper (2-5 cm below the surface).

Nutrient requirements

Little specific information available for hydroponics.

Suitable systems

Depends on the type of iris. Some types require very little aeration and will grow completely submerged in water, others do not.
Iris laevigata needs to be in extremely we conditions to thrive. It would be best suited to water culture or perhaps tried in a medium such as 40% vermiculite and 60% perlite.
Iris germanica requires a very well aerated situation. The author has grown these successfully with minimal irrigations.
Dutch, Spanish and English irises generally like a drier, better-drained medium than average. These would be best tried in sand or gravel beds.

Planting

Plant bulbs or rhizomes direct into hydroponics.

Special cultural techniques

Some support system is necessary.

Problems

Overwatering will cause bulb or rhizome rot.
Pest and disease problems include snails and slugs, aphis, thrip, bulb flies, viral diseases, leaf spot, ink spot and iris rusts.
Frost can be a problem with some types.

Harvest

Cut when flower begins to appear in the flower.

Varieties

Irises are classified as follows:

1. Bulbous types
   a) Xiphiums (Dutch, Spanish, English)
      These are popular as cut flowers worldwide.
   b) Early flowering and small Reticulatas
   c) Junos varieties

2. Rhizome types
   a) Bearded
      Have fleshy rhizomes and large wide bladed leaves.
      These generally prefer warm, dry conditions.
   b) Beardless
      Narrower leaves and smaller fibrous rhizomes.
   These prefer wet situations.
   c) Crested
      Thin rhizomes.

iris

Lisianthus Gentianaceae

Growing conditions

Optimum temperatures are above 16°C and below 25°C.
Good drainage is essential.
Long days promote flowering.
Most commercial production is in greenhouses, although open field production is possible in warmer areas. Some protection from heavy rain is beneficial.
Shading is highly beneficial.
Supplementary lighting (4500 lux minimum) and heating is required in most areas for winter production.

Nutrient requirements

pH 6.3 – 7.0.
Lisianthus prefer high levels of calcium and adequate phosphorus.
1-1.2mS/cm in summer and 1.5-1.6mS/cm in winter.

Suitable systems

Has been grown successfully in fine sand mixed with rice hulls.
Coarse, free-draining bark or cocopeat may be suitable.

Planting

Propagated from seeds. High temperatures during propagation cause rosetting (clustering of leaves and short internodes on the stem).

Problems

Root diseases, especially pythium, can be a significant problem. Outdoor crops in areas with heavy summer rain are very prone to root rots.
Leaf diseases that may need spraying include downy mildew and botrytis.
Thrips can be a problem.

Harvest

Plants are usually cropped twice. The first flowers are picked at around 12 weeks, with a second crop picked 7-8 weeks later. After the second crop the plants begin to lose vigour.
Place flowers immediately into a coolroom.

Narcissus (Daffodil, Jonquil) Amaryllidaceae

Growing conditions

Require cool conditions with daily maximums not over 21°C and preferably not over 18°C. Higher temperatures may be tolerated at the end of the growth cycle.

Nutrient requirements

High light intensities can increase iron requirement.

Suitable systems

Aggregate culture is suggested as having the best potential. Narcissus have been grown successfully in 40% perlite and 60% coarse granitic sand.

Planting

Plant at a depth equal to three times the bulb's thickness.

Special cultural techniques

Horizontal trellis support.

Problems

Pest and disease problems can include mites, bulb flies, slugs, viruses, and various fungal rots and leaf-marking diseases.

Harvest and post harvest

Harvest any time from when colour appears in the swollen flower bud (just before or immediately after the flower opens).

Orchids Orchidaceae

Orchids are a very large group of plants which vary greatly in appearance and growth requirements. Cymbidiums are the only orchids we know of which have been grown commercially in hydroponics.

Growing conditions

Must have excellent aeration and perfect drainage..
Cymbidiums require temperatures between 15°C and 25°C, and full light for good growth when young.
Minimum temperature for cymbidiums should be 10°C.
Flowers are initiated during a period of 21°C day temperatures and 14°C night temperatures over summer.
Good ventilation (air movement) around plants is important.
Some types have a semi-dormant period of growth (eg. dendrobiums) while others, if given optimum conditions, will grow continuously (eg. cymbidiums).

Nutrient requirements

pH should be around 5.5 for cymbidiums.
Some nitrogen is supplied as ammonium salt to help kept the pH low.
Keep solution at low concentrations of around 0.8 mS/cm or lower.
Sodium and chloride levels must be kept low.
Sulphate content is kept low to stop EC from going too high.

Suitable systems

Traditionally cymbidiums have been grow in peat-based mixes. In Europe there has been increased use of granular rockwool.

Only rockwool or material with no cation exchange capacity should be used, to minimise salt build-up (see below).

Planting

Grow in individual containers fed by drippers.
As the plants grow in size, the container size and spacing can be increased. Three-year-old plants in 10-litre containers are spaced at 8 plants per square metre; five-year-old plants in 20-litre containers are spaced at 3 plants per square metre.

Problems

Be careful to remove all peat or bark from the roots when transplanting into hydroponics. Residues of such material in a hydroponic medium can attract deposits of salts from nutrient solution. This build-up can eventually reach toxic levels and damage the plant.
Various pests and diseases occur and need to be controlled, including root rots, viruses, mealy bug and aphis.

Harvest and post harvest

Harvest before buds are fully opened.
Cymbidiums will yield up to 90 blooms per square meter per year at five years of age in a good operation.

Rose Rosa sp. Rosaceae

Growing conditions

Good aeration and drainage are vital.
Light intensity must be good, but excessive hot sun will cause scorching.
Ideal temperatures are 15-27°C.
Ventilation may be necessary to avoid exceedingly high humidity.
Roses tolerate a very wide range of temperatures and have been grown successfully out of doors from the tropics to some of the coldest temperate regions.

Nutrient requirements

pH 5.5 to 6.
EC around 1.5 mS/cm (roses do not tolerate high salt levels).
A suitable nutrient solution would be as follows:

NUTRIENT	PPM
Nitrogen (as nitrate)	160
Iron	1.4
Manganese	0.3
Phosphorus	50
Zinc	0.2
Potassium	230
Boron	0.2
Calcium	160
Molybdenum	0.05
Magnesium	20
Copper	0.04

In recent times are more concentrated nutrient solution has been used by some growers who claim better cropping at EC readings of up to 2.5 or higher.
Avoid excessive salt build-up (run-to-waste systems need frequent irrigations to leach out excess unused salts).

Suitable systems

Perlite.
Granulated rockwool.
Rockwool slabs - the way drainage from the slabs is handled is a critical factor in achieving high productivity. 10 cm deep slabs have proven more successful than 7.5 cm depth.
In Europe, slab heating is frequently used to achieve cropping though winter.
An excess of nutrient solution is normally applied, aiming for a run-off of 15%, or more if conductivity becomes too high.
Over winter, irrigations may be gradually reduced to a level which barely keeps the roots moist while the plants are dormant. Irrigations should return to normal when new season's growth starts.

Planting

Space plants at least 0.5 m apart.
Only use budded or grafted plants.
The plants are usually purchased as bare-rooted plants with roots wrapped in sawdust of moss. The best time to buy is early winter. Place orders with wholesale nurseries at least six months in advance to be sure of quality plants and the desired varieties.

Special cultural techniques

Regular pruning is essential. Prune hard in cold climates and lightly in warm climates.

Problems

Several diseases including black spot, fusarium, pythium, rust, phytophthora and viruses.
N.B. Fongarid can cause leaf scorch.
Aphis is the most significant pest problem.
Other pests include chafer grubs (on roots), borers, scale, caterpillars, leaf miner, leaf hopper, thrip and red spider mite.
Flower buds sometimes fail to open. Wet or shaded conditions are the most common causes.
Purple to brownish spotting on foliage can be caused by either poor drainage or use of a copper-based spray.

Harvest and post harvest

Harvest swollen buds as colour shows through, before they burst open.
In New Zealand, greenhouse roses grown on a 30 cm grid produce 20 blooms per year per plant (ie. approximately 220 blooms per square metre).
In Israel, with over six months of cropping, yields of 200 blooms per year per square metre have been achieved.

Varieties

Hybrid Tea roses are the most commonly used for cut flowers. Floribundas are also used for cut flowers, but not to the same degree.

matthiola incana stock

Stock *Matthiola incana* Cruciferae

Growing conditions

Requires cool temperatures, preferably not over 24°C.
Requires temperature below 16°C for flowering to be induced.
Tolerates reasonably moist (but not over-wet) conditions in both air and root environments.

Grows well in either sun or light shade.

Nutrient requirements

Adequate calcium and potassium are important.

pH 6.0 to 7.0.

Suitable systems

Relatively easy to grow in rockwool or most aggregate systems.

Planting

Sow seed direct or transplant seedlings started in vermiculite, perlite or rockwool propagating blocks.

Problems

Aphis can become a problem on mature plants.
Seedlings are susceptible to fungal diseases if they become too wet.

Harvest and post harvest

Store at 10°C or a little lower after harvest.

CHAPTER 15 : OTHER CROPS

INDOOR PLANTS

African violet *Saintpaulia sp.* Gesneriaceae

Growing conditions

Minimum temperature of 15°C, a relatively even temperature with no cold draughts or other sudden temperature changes.
Bright light (day length of 16 hours or more is needed for flowering).

Nutrient requirements

Maintain a lower EC than many other plants.
pH 6.0 to 7.0.

Suitable systems

Self watering pots with aggregate are very successful.
50/50 sand and perlite, expanded clay and scoria have been successful.

Planting

Propagates readily from leaf cuttings in 40% perlite and 60% coarse granitic sand.
Has potential to sell as a flowering container plant growing in a hydroponic pot.

Special cultural techniques

Remove dead flowers and older marked leaves.
Do not allow water to get on the foliage.

Problems

Markings on leaves are commonly caused by adverse environmental conditions; especially if strong sunlight hits a leaf with water on its surface.
Fungal diseases include crown rot (occurs with overwatering), botrytis and powdery mildew (which occur when leaves are sprayed with mist).
Pest problems include whitefly, mealy bug and mites.

Anthurium Araceae

Growing conditions

Minimum temperature of 15°C, optimum growth is between 18 and 21°C.
Bright light is required in winter, but summer shading may be necessary.
Humidity is important (misting helps in dry climates).
Root zone temperature and moisture must be maintained at constant levels, hence a freely draining medium with good insulation properties is best.

Nutrient requirements

pH 5.0 to 6.0.

Suitable systems

Has been grown successfully in high quality peat. Perlite or mixtures of sand with vermiculite or perlite should be suitable in self watering pots. Be careful not to use a medium which becomes too wet though.
Can be grown for commercial sale as a container plant, or a cut flower.

Planting

Propagated by division when temperatures are around 21°C.

Special cultural techniques

Remove spent flowers or damaged leaves.

Problems

Low humidity leads to poor flowering, brown leaf tips and curled leaves.
Low temperature can cause yellowing of foliage.
Pests can include mealy bug, aphis and scale.
Fungal diseases can rot roots in over wet conditions.

Harvest and post harvest

If grown as a cut flower, flowers are cut when 75% open, stood in preservative solution and stored at 13°C. They will keep for up to four weeks with regular changes to the solution.

anthurium

Aphelandra Acanthaceae

Growing conditions

Minimum temperature of 12°C, a preferred temperature of 18°C, and high humidity, bright light but not direct sunlight, constant moisture and good aeration.

Nutrient requirements

Heavy feeders.
pH 5.0 to 6.0.

Suitable systems

Aggregate culture in 50-70% sand mixed with peat, vermiculite or perlite, or in pure perlite, expanded clay or scoria.

Planting

Propagate by 8 cm tip cuttings in late spring.

Special cultural techniques

Minimise watering at lower temperatures when growth slows to prevent root rots.

Problems

Pests include aphis and mealy bug.

Bromeliads Bromeliaceae

Growing conditions

Most will tolerate temperatures as low as 9°C, some will tolerate much lower temperatures, but not frost.
High temperatures (over 25°C) are required to initiate flowering.
Bright light is important, but not direct sunlight.

Nutrient requirements

Nutrient requirements are relatively low.
pH 5.0 to 7.5.

Suitable systems

Most types of aggregate culture are successful.

Planting

Propagate from offset division.

Special cultural techniques

Remove dead flowers and leaves.

Problems

Bromeliads have few problems.

Caladium Araceae

Growing conditions

Temperatures should never be below 15°C and preferably always above 21°C.
Moderate light requirement (no direct sunlight).
High humidity, good drainage and even root zone temperature.

Nutrient requirements

pH 6.0 to 7.5.

Suitable systems

Well-draining, well-insulated aggregate media such as perlite would probably be best.

Planting

Plant tubers early spring.
Propagate by removing developing tubers from parent plant.

Special cultural techniques

As foliage dies back in autumn, lift tuber, trim off foliage and roots and store at 15°C until early spring.

Problems

Several fungal and insect problems can occur. Many of these are more likely to become serious when the plant is weakened by adverse environmental conditions.

Dieffenbachia Araceae

Growing conditions

Temperature never below 15°C, bright light in winter but partial shade in summer, high humidity and warmth are essential for best results.
Root environment should be constantly moist and well aerated.

Nutrient requirements

High nitrogen requirement.
pH 5.0 to 6.0.

Suitable systems

Aggregate and water culture have been successful.

Planting

Propagate by tip or stem cuttings.

Problems

Pests include scale and spider mites.
Excess water can cause stems to rot or discolour.
Cool temperatures or excess light can cause yellowing of foliage.

Dracaena Agavaceae

Growing conditions

Temperature preferably not below 13°C, ideally 18-24°C.
High humidity, light summer shading and constant moisture in the root zone are important.

Nutrient requirements

pH 5.0 to 6.0.

Suitable systems

Most types of aggregate culture should be successful. A heavier medium (eg. scoria or expanded clay) may be preferable to give better anchorage.

Planting

Propagate by stem cuttings.

Special cultural techniques

Some form of support may be needed, particularly in lightweight media.

Problems

Too much water or excessive cold are the main reasons for death.
Several pests and diseases can occur.

Ferns

Growing conditions

Ferns vary greatly in temperature requirements according to variety.
Most grow well between 16°C and 21°C.
Most respond well to moderate light (but not bright light), prefer high humidity and constant moisture in the root zone.

Nutrient requirements

pH requirement varies but most do well at 6.0.

Suitable systems

Luwasa self-watering pots with expanded clay aggregate have been used successfully.
Perlite and peat have been successful with many ferns.

Special cultural techniques

Many ferns are deciduous and their foliage will die back for a period of the year. These are more susceptible to root rot fungi if kept too moist when devoid of foliage.

Problems

Many pest and disease problems occur, including scale, mealy bug, caterpillars, aphis and snails.

Ficus Moraceae

Growing conditions

While many are relatively cold tolerant, most are best kept at temperatures above 15°C.
They have relatively low water requirements but prefer high humidity.

Nutrient requirements

pH 5.0 to 6.0.

Suitable systems

Best in a clay aggregate such as gravel, scoria or expanded clay.

Planting

Propagate by cuttings or layering.

Problems

Mites thrive in low humidity. Scale can also be a problem.
Excess water can lead to fungal root and stem rots.

ferns

Impatiens Balsaminaceae

Growing conditions

Bright light but not direct hot light in summer.
Ideally temperatures around 24°C and preferably never below 12°C.

Nutrient requirements

pH 5.5 to 6.5.

Suitable systems

Most aggregate systems are suitable.

Planting

Propagate by cuttings or seed.

Special cultural techniques

Remove dead flowers.
Prune back hard annually, just before new season's growth.

Problems

Excess water can result in rots developing.
Pests include thrip, aphis and mealy bug.

Monstera Araceae

Growing conditions

Ideally 21°C though relatively cold tolerant (but not frost tolerant).
Needs well-aerated freely-draining root environment which is never too wet.
High humidity is desirable but not necessary.

Nutrient requirements

pH 5.0 to 6.0.

Suitable systems

Heavier coarse aggregates are best for both maintaining preferred moisture levels and giving good anchorage.

Planting

Propagate by layers or cuttings.

Problems

Relatively few except excess water in the root zone.

Palms Palmaceae

Growing conditions

Ideal temperature varies according to variety though most prefer over 15°C, ideally over 20°C.
Good light is important, though some shading may be needed in summer.
Excellent drainage is important.

Nutrient requirements

Though palms respond to high levels of feeding, it has been shown this increases the rate of metabolism and shortens the period they can be kept indoors.
pH 6.0 to 7.0.

Suitable systems

Scoria, gravel, sand or expanded clay are most likely to suit.

Planting

Some palms are slow to propagate from seed (sometimes taking several years to germinate).

Special cultural techniques

Need to be rejuvenated in a greenhouse or shadehouse every 1 to 3 years.

Problems

Pests include mealy bug, scales and mites.

palm

HERBS

Basil (Sweet) *Ocimum basilicum* Lamiaceae

Basil foliage is sold as a fresh-cut herb for culinary use or processed for the oil which is used in cosmetics, soaps and processed foods.

Growing conditions

Ideally around 20-24°C.
Needs continually moist but well aerated root environment.
Needs good light conditions, although some shade may be needed in summer.

Nutrient requirements

pH 5.5 to 6.5.

Suitable systems

Has been successful in NFT (7-8 cm channels), scoria and sand/peat.
Should be successful in rockwool.

Planting

Seed germinates in 4 to 7 day at 21°C in rockwool cubes or perlite.
Plant out at 20 cm spacings in early spring.

Special cultural techniques

Trellis support is needed.

Problems

Vigorous roots can clog NFT channels after a while.

Harvest and post harvest

Harvest before flowering starts.
For the first harvest remove tips with one to two nodes. Side shoots will develop and a second harvest can be made about a month later. Further harvest can be made until mid-autumn when the crop is removed.
Harvest in the morning when cool and place immediately in a cool place at around 5°C.

Lemon Balm *Melissa officinalis* Lamiaceae

Though not grown widely as a commercial crop, the lemon-flavoured foliage is an excellent lemon substitute as a tea or in food processing.

Growing conditions

Will take full sun but prefers some shading, dry air environment is preferable.

Nutrient requirements

pH 5.5 to 6.5. Will not grow at pH below 4.5.

Suitable systems

Aggregate culture, NFT or rockwool should all succeed.

Planting

Propagates easily from seed or root division in late winter or early spring.
Space at 30-40 cm.

Special cultural techniques

Trellising and wind protection are necessary.

Problems

Foliage can turn brown if it gets wet at night.
There are relatively few pest or disease problems.
White fly and aphis have occurred though.

Harvest and post harvest

Harvest in cool time of day and package in plastic to reduce moisture loss.
Keep out of direct sunlight and at a low temperature to reduce condensation (which promotes fungal problems).

lemon balm

Marjoram *Origanum majorana* Lamiaceae

Sold as dried leaves for culinary purposes, or extracted oil which is used in cosmetics and foods. Oregano which is closely related (and grown similarly) is preferred for use in herbal medicines.

Growing conditions

Must be well aerated but constantly moist around the roots.

Nutrient requirements

pH ideally 6.0, never below 5.0.

Suitable systems

NFT has been successful.
Sand, gravel, perlite and rockwool are also recommended.

Planting

Seed germinates easily in about one week at 20°C.

Problems

Aphis may be a problem.

Harvest and post harvest

Make the first cut when 'ball-like' growths appear on the stems. Cut back to within 3 cm of the base. The regrowth that occurs generally gives the best crop. Further harvests can also be made. Most of the oils are retained in dry leaves, though they should be stored in airtight containers and kept in the dark.

Mint *Mentha sp.* Lamiaceae

Several species are grown commercially, mainly for oil production. Peppermint which yields menthol is the most widely grown. Though generally cultivated in soil, there may be potential for hydroponic farming.

Growing conditions

Adapts well to wet conditions with medium aeration, grows well at mild temperatures (15°C to 20°C).

Nutrient requirements

pH 6.5 to 7.0. Will not grow at a pH level below 4.5.

Suitable systems

NFT has been very successful.

Planting

Plant cuttings or divisions in late winter.

Problems

Common pests include cutworms, caterpillars, flea beetles, aphis, mites and root weevils.
Verticillium wilt can be a problem.
Vigorous root system can block NFT channels. Plants should be replaced periodically.

Harvest and post harvest

Mint cut for the fresh market should be kept cool (5°C), out of the sun, and not bruised at all (this accelerates fungal damage). Store at 95% humidity or wrap to prevent moisture loss. Keep out of direct sun.

Parsley see Vegetable Chapter

Rosemary *Rosmarinus officinalis* Lamiaceae

Growing conditions

Well-aerated mildly-moist (never saturated but never dry) root environment.
Temperatures below -2°C will cause death; prefers full sun or slight shade.

Nutrient requirements

pH 5.5 to 6.0.

Suitable systems

Has been successful in NFT.
Will grow in sand, gravel or perlite.

Planting

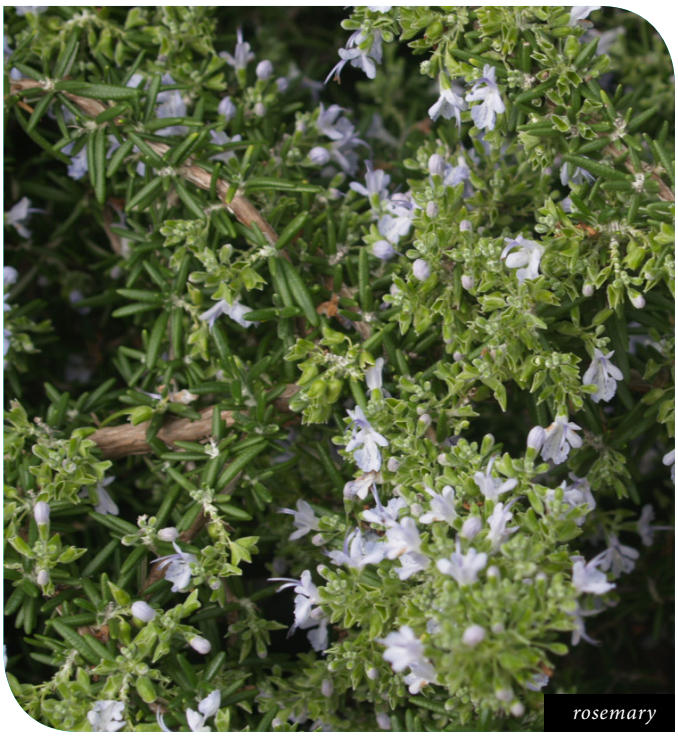
Space at 0.5 m intervals.

Problems

Rosemary has few problems.

Harvest and post harvest

Foliage is marketed for use fresh or dried for culinary purposes. Oil is a highly marketable commodity.



rosemary

Sage *Salvia officinalis* Lamiaceae

Growing conditions

Requires good light conditions.
Requires excellent aeration but also constant moisture (it will die if the medium around the roots is dry).
Ideally temperatures should be between 18°C and 24°C.

Nutrient requirements

Will not grow at a pH below 4.0.

Suitable systems

Has been successful in NFT.
Is likely to grow best in coarse aggregate.

Planting

Propagate from seed or cuttings.
Space 30-50 cm apart.

Special cultural techniques

Wind protection is important and trellising may be beneficial.

Problems

There are few problems, though aphis infestations occasionally occur.

Harvest and post harvest

Leaves are harvested and sold fresh or dried. Oil is extracted commercially.

Thyme *Thymus vulgaris* Lamiaceae

Growing conditions

Ideal temperature is 20°C to 24°C.
Media should be well drained but always moist.
Full sun is desirable though summer shading may be beneficial to control temperature in summer.

Nutrient requirements

pH 5.5 to 7.0. Will not grow at a pH below 4.5.

Suitable systems

There has been difficulty with NFT.
Sand, gravel or rockwool may be more successful.

Planting

Depending on variety, usually space at 15 to 20 cm.

Problems

Few pests and diseases.
Occasionally aphis is a problem.

Harvest and post harvest

Cut foliage back hard periodically, and harvest growth periodically.

GRASS

Fodder

Grass and other fodder crops for animals have been grown successfully in hydroponic installations. Common agricultural practice involves grazing animals in fresh grass in the warmer months and feeding them with dry, cut fodder in the cooler months. A distinct advantage of hydroponic fodder is that it can be produced year round, giving animals fresh green food over winter.
The protein content of some fodder varieties grown hydroponically is significantly higher than when the same plants are gown in soil. Farmers in several countries have claimed an increase in milk yields from cows fed on hydroponic fodder.
Depending on the animal, between 5 kg and 10 kg of fresh fodder will be eaten per animal per day.

Growing conditions

Optimum temperature depends on variety, but usually around 20°C to 24°C.
Good light intensity is important.

Nutrient requirements

Most grasses prefer a pH of around 6.0.

Suitable systems

NFT – Using wide channels (20-30 cm), a sheet of water-absorbent paper is laid in the channel base to give a capillary-matting effect. Seed is sown on the sheet. The solution flow should be continuous but not so strong that it moves the seed. The top of the channel remains exposed to light. Once the seed has germinated and grown into the paper, the flow rate can be increased (the roots and grass blades will restrict the water flow, requiring an increasingly stronger flow rate).
Plants can be recut later for more fodder.
Progressive cropping of the same plants is an option, however disease can build up and flow become restricted to the point where a fresh sowing becomes necessary.
Peat bed – A shallow bed of peat can be seeded and sub-irrigated. Plants can be cut or lifted as a matted sheet for use.
Other methods – Most other types of aggregate bed can be used, though the plants must be cut. Be careful not to get media such as perlite or vermiculite mixed with fodder as these materials can harm animals which eat them.

Special cultural techniques

Multi-level systems – Fodder can be grown in several layers on racks in a shed or greenhouse with the use of artificial lights. (NB. You must use the proper wavelength light source, such as Grolights.)

Problems

If using paper as a capillary mat, be sure it doesn't contain newsprint or any other source of phytotoxic chemicals.

Varieties

The following have been grown successfully in hydroponics: oats, wheat, rye, barley, sorghum.

Chitted Seed for Turf

Chitted seed is pre-germinated lawn seed. Hydroponic systems can be used to commence germination prior to sowing.
This process usually takes up to one week. Seed is removed from the system and sown when roots have emerged but before cotyledons have fully opened on most seeds.

Growing conditions

Depends on grass variety, but generally as for forage crops.

Nutrient requirements

pH 6.0.
Nutrient solution is not needed as the seed has a store of food.

Suitable systems

Sprinkle a thin layer of peat, perlite or vermiculite on black plastic sheets on the floor of a greenhouse in winter. Mix in grass seed. Water until thoroughly moist. Keep wet but not overwatered for 5 to 7 days then remove and sow the seed as you would do normally for a lawn.

Planting

The area can be aerated then chitted seed raked into the holes by the aerator.
Seed can be spread then covered with a layer of topsoil.

Problems

Rough handling can damage seed.
Chitted seed is extremely susceptible to drying out and dying with the first week following planting. It must be kept well watered.

turf

PROPAGATION/NURSERY PRODUCTION

Hydroponics has been used commercially for plant propagation in a number of situations around the world. Aeroponics, rockwool propagating blocks, perlite, gravel culture, and even NFT have practical applications for striking cuttings and raising plants for selling bare rooted. In some respects tissue culture (micro propagation) could be considered a form of hydroponic culture.

Rockwool propagation blocks have also been successfully used for germinating and raising seedlings. Rockwool is first watered, then seed pushed with a dibber (stick) slightly below the surface. There has sometimes been a problem though with smooth-surfaced large seed (eg. legumes). As the rockwool dries, it can contract, forcing larger seeds to the surface, where the germinating seeds may dry out and die. If the blocks are kept moist and inspected regularly, this can be avoided.

From time to time, successful hydroponic propagation has been reported in *International Plant Propagation Society Conference Proceedings*. Some interesting reports are listed below:

1. IPPS Volume 39 (1989)
   "Production of Spray Chrysanthemums in a Hydroponic System" by Anthony Herve, Langtree Nursery, South Australia. (NFT)

2. IPPS Volume 53 (1991)
   "The Rooting of *Daphne odora* Thunb. Cuttings in a Hydroponic Production System" by Boland and Hanger, Knoxfield, Victoria. (Polypropylene beads in a NFT channels)

3. IPPS Volume 42 (1992)
   "Hydroponic Propagation of Aglaonema" by Neville Raward, Queensland. (Sub irrigation, Gravel Culture)

4. IPPS Volume 45 (1995)
   "Sweet Potato/Virus Free Propagation in Hydroponics" by Ohta and Bekki, Japan
   (Deep Flow Technique)

Other Crops

Sholto Douglas (in *Advanced Guide to Hydroponics*) suggests the following are well suited to propagating in hydroponics: cocao (*Theobroma cacao*), coffee (*Coffea Arabica*), sugar cane (*Saccarum officinarum*), runner (*Hevea brasiliensis*), tea (*Camellia thea*) and tobacco (*Nicotina tabacum*).

He gives specific recommendations and claims that frequently the quality of young plants produced is far better when they are started in hydroponic culture.

CHAPTER 16 : MANAGING A COMMERCIAL HYDROPONIC FARM

Growing plants in hydroponics is one thing, but operating a viable hydroponic farm is altogether another.

Commercial hydroponics is not just about setting up and operating hydroponic systems. If you are to be successful and run a viable operation you must learn to do a number of other things:

- Select the right crops to grow
- Have a workable physical layout
- Manage your staff and finances properly
- Market your produce properly.

DECIDING WHAT PLANTS TO GROW

When deciding what plants to grow in a commercial hydroponics farm, consider the following:

- Ease of propagation/cost of transplants. What will it cost to get your initial plants (in time or money)? If you plan to propagate yourself, how easy are the plants to propagate? Are the plants readily available? Is the recommended planting time the same as the time of year you plan to start your operation?
- How easy are these plants to grow? Do you or your staff have the expertise to grow these varieties? Difficult plants may be more costly to grow, and more risky to get a profit from, unless you have better than average skills.
- How long will the crop take to grow? Some plants produce a crop ready to sell within months, others take many years.
- Suitability to your facilities. Do you have the right buildings, equipment and other facilities to grow the particular plants under consideration? Do you have the money and space to provide those facilities?
- Suitability of climate. What plants are most suitable to grow in your climate?
- Your environment. It is always more efficient to work with the environment rather than trying to recreate different environments.
- Are other competent growers already producing the crop you would prefer to grow? Can you establish a fair share of the market?
- Distance from potential markets. Transport is costly, and can be risky. What other alternatives are available?
- Are profits (in addition to wages) likely to be an adequate or reasonable return on your investment in terms of time and money?
- The skills of your staff. Don't try to do what you are not skilled to do. Someone with better skills will probably do it better and cheaper.

RUNNING A CROP TRIAL

Growers are advised to conduct a field trial before growing any new crop or cultivar on a commercial basis. Too often growers spend a lot of money, time and effort setting up a system only to find the crop underperforms or even fails. A field trial avoids many such problems by allowing the grower to assess and compare different crop treatments on a small scale before embarking on a full-scale effort.

Examples of crop trials commonly used by growers include trialing different crops, evaluating new cultivars, and comparing growing media or feeding strategies.

Basics of Setting Up a Comparison Trial

A crop trial is basically an experiment that allows the grower to make comparisons between different treatments. The treatment might be an adjustment to a nutrient solution, trialing a new cultivar, trying out a different growing medium, etc.

The design and analysis of a meaningful crop trial will often require the help of a professional horticultural consultant. Before setting up the trial, the grower needs to decide on the size of the trial and the number of treatments (e.g. comparisons between new cultivars or different levels of a nutrient) to be tested. It is preferable to keep trials simple with minimal treatments to be tested.

All plants in the trial are divided into 'plots', with each plot consisting of a group of plants in the same location receiving the same treatment. For each treatment tested, one group of plants is a control plot, which receives the grower's usual management program. The other groups of plants also receive the identical management program, except for the actual treatment itself. The purpose of the control plot is to enable a comparison to be made with the treatment plot(s).

'Guard plants' are placed around the outside edge of the trial area. Their purpose is to prevent edge effects that may influence growth of plots on the outside of the trial. The guard plants do not form a part of the trial – they are part of the materials used to carry out the trial.

Plot positions must be done randomly to exclude experimental bias. Bias can be introduced into an experiment if the grower selects conditions for the treatment and control plots in a non-random fashion. A simple way to allocate plot positions is to number the plots, and then use a random number generator on a hand calculator to allocate plots.

Running the Trial - Records and Recording

There are many measurements that may give valuable data, including solution analyses, foliar mineral analysis, plant height, leaf area and leaf area index (LAI), root dry weight, plant dry weight versus fresh weight, fruit quality assessment, water uptake, yields, marketable yields, taste quality assessment, shelf life and photographs. There may be a number of characteristics that the grower wishes to assess.

Evaluating the Trial

The crop trial is evaluated by comparing the control plot against a treatment or a number of treatment plots. The assessment of the trial usually depends on statistical analysis which determines whether observed differences between control and experimental plots are likely to be due to real differences or chance occurrence.

Replication of plants and plots is commonly used to improve statistical evaluation. The higher the number of replications, the lower the margin for error in the trial.

In evaluating the trial, standard statistical analysis should be used to determine the true result of the trial. Simply looking at the plants and drawing a conclusion from them can be misleading. It is much more useful to quantify the trial by counting plants and carrying out a statistical analysis of the data in order to determine whether any observed effects are significant. In order to do this, the grower may need to employ the services of a statistician or horticultural consultant.

CROP SCHEDULING

Throughout the life of any crop, you will need to perform a number of operations. It is often helpful to break down the growing period into weeks, designating the tasks which are to be undertaken each week. Obviously the actual time of carrying out any task will vary a little according to the changes in the weather and different varieties of plant etc.

Example of a Simple Flow Chart for Growing Lettuce

Week 1 Sow seed in 75% sand and 25% peat and place in greenhouse

Week 2 Check for germination. Keep well watered.

Week 3 Check for damping off, thin out if necessary. Spray fungicide if necessary.

Week 4 Plant seedlings into NFT channels. Spray with insecticide (malathion) for caterpillars etc.

Week 5 Check for insect and fungal problems. Remove affected leaves and plants, or spray.

Week 6 Treat with fungicide

Week 7-8 Check for disease, insect damage and nutrient deficiencies.

Week 9 Harvest.

Obviously some crops involve more work – pruning, changing nutrient solutions, shading, temperature control, staking, etc. Any such tasks should be included in a flow chart. This type of analysis of the crops's life will help you plan your production.

lettuce

STANDARDS

A hydroponic farm, like any business, must set and adhere to certain standards if it is going to operate profitably. These standards can be broken down into three main groups:

1. Cost of efficiency standards
2. Quality standards
3. Quantity standards

Cost Efficiency

There must be a sound relationship between the cost of production and sales price. Both of these monetary figures must be constantly monitored and maintained at an acceptable level so as to ensure profitability in the business.

Cost of Production + Profit = Sales price

If the cost of production gets too high, profit will decrease. In such a situation, the sales price must be increased, or else the profit figure can become a minus amount (i.e. you might be losing money rather than making it).

In order to control your cost effectiveness, you must be aware, and in control of all factors which influence the cost of production.

Cost of production

Cost of production is influenced by the following factors:

- Cost of site (lease/rent value)
- Cost of site services (power, gas, water, insurance, rates, etc)
- Cost of materials (soil, fertilisers, etc)
- Cost of unsold produce – a certain proportion may be lost, may die, or may just become unsaleable. (Some horticultural businesses budget for as much as 30% of stock being thrown away.)
- Labour costs (be sure to include your own time as well as employees).
- Advertising promotion (printing, advertising in magazines, etc.)
- Selling costs (transportation, invoicing, etc.)
- Taxation (don't forget payroll tax, income tax, etc.)

Profit

This figure should be over and above money which you earn as wages. If you are only working for wages (with no profit), then you would be better off putting your money into some different form of investment and going to work for someone else.

Profit should be greater than the interest rate which you could get by investing your money elsewhere. Profit should normally be at least 15-20%. In horticultural businesses the profit margin can vary greatly from crop to crop and year to year. You will find that profit will be very low (possibly nothing) some years, and high other years.

The profit must be viewed in term of an average over several years. New operations should always have sufficient liquidity to carry them over if they have a couple of bad seasons before some good seasons come along.

Sales price

The figure which produce is sold for can vary considerably. This can due to such factors as overall economic conditions, general availability of the product you are selling, and consumer demand.

Quality Standards

The following factors are of concern when considering produce quality:

- General appearance of vigour or health such as markings or lack of markings (e.g. disease, rot, bruising, etc.)
- Taste or smell (e.g. how sweet or bitter)
- Freshness (i.e. the quicker you can sell it after harvest, the better the quality will be).

Quantity Standards

Commercial production must achieve certain standards in terms of the quantity of produce being harvested, its weight and the size of each individual unit (e.g. how many strawberries will you pick per year per square metre, and how big will each strawberry be).

- For some crops, the size is not critical but the number is (e.g. orchids are sold on the number of flowers. A slightly smaller or larger flower will not make a great deal of difference to the cost).
- For other crops, weight is critical, but size doesn't matter (e.g. beans are sold by the kilogram, irrespective of whether they are large or small beans).
- For other crops size and weight are both important (e.g. strawberries are sold by the kilogram, but large ones are sold at a different rate from small ones).

spinach

HYDOPONICS FARM LAYOUT

A well laid out system will be more efficient, less costly to operate in terms of manpower and will return greater profits. It is essential that equipment, materials, and people are able to move easily from one area to another. To achieve this you should do the following:

- Study the work operations which take place.
- Identify movements that occur the most (e.g. People and equipment may move from the store room to the nutrient tanks more frequently than from the nutrient tanks to the packing sheds).
- Design the farm in a way that makes movement easiest along the paths which are used the most (e.g. Nutrient tanks should be closer to the store than to the packing sheds).
- There are three aspects to work carried out on any hydroponics farm: growing, harvesting and marketing. These three areas should be segregated as much as possible.

Good layout decisions based on the above principles are as follows:

- Tools, equipment and chemicals used in production should be kept away from the marketing side of the operation.
- Delivery vehicles should have easy access to the property, and deliveries should be able to be made as close as possible to store rooms or sheds.
- Delivery vans, staff cars and vehicles transporting produce should have restricted access to the property. In general, these vehicles not only take up space, but they bring disease into the property, as well as being a security problem. Consequently, loading and unloading bays are best situated close to the front of the property.
- Post-harvest operations including sorting, grading, packing and storage should be done under cover to protect produce, and should be located within easy reach of the crop. It should be possible to move produce into this area quickly and easily after harvest.
- Concrete or asphalt pathways and floors should be used in areas where wheeled tools or equipment are to be used or areas which must remain clean (e.g. a path leading to a greenhouse should preferably be sealed to keep shoes clean and reduce the chance of disease being carried into the house).
- Potentially dangerous situations should not be allowed (e.g. objects protruding into work areas and access tracks – overhead objects should not be so low to restrict clear access).

Design of a Store

A storeroom or storage shed must be accessible from other parts of the farm, be secure and have an interior design which allows for easy access to stores.

- Both expensive and dangerous items can be stored on a farm. The store should be securely locked and there should be a limit on staff who have free access.
- Doors of small stores should open out allowing better access inside.
- Pesticides or other dangerous chemicals should be stored in a separate lock-up cupboard or room. This is often required by law. There may also be legal obligations to place danger signs on such storage areas.
- It is preferable that all equipment and materials, where practical, be stored on racks or shelves, off the ground (for cleanliness), and properly labelled where necessary.

Trays of young plants on capillary mat

MARKETING YOUR PRODUCE

Marketing takes in everything involved in the process of taking your produce to the final customer. If you are to market your produce well, you need to understand all the steps in this process, and make sure each step is done as well as possible.

Typical steps in marketing are:

- Packaging and storing the produce – this affects its attractiveness to potential buyers and its longevity.
- Transporting the produce.
- Promoting the produce.
- Selling.

Considering Your Markets

Hydroponic produce, whether fruit, vegetables or cut flowers, is generally sold through one of the following:

1. Direct sales to the public
   (e.g. from the packing shed on your property, or from a roadside stall). Some growers have supplemented their income by tapping the tourist market and catering in other ways to people visiting their property. It may be viable to consider setting up conducted tours of a hydroponic farm together with direct sales of produce, and perhaps a shop selling souvenirs, refreshments etc.

   Some such operations may involve 'pick your own' sales where the public pays a bargain price for what they pick themselves. This has been done commercially with NFT strawberries in Australia.

2. Sales through major markets
   Major cities operate fruit, vegetable and cut-flower markets through which growers sell produce to shopkeepers. You can hire a stand or sell through an agent (who generally takes a commission) at such markets.

3. Selling direct to retail outlets
   It may be viable for you to do your own distribution with some crops, and if you are big enough to make it worthwhile. Distribution can be expensive and time consuming though, and should not be tackled lightly.

4. Contract growing
   Some companies will contract produce to be grown for processing in factories. Generally the price paid for produce is predetermined, limiting the mount of profit which the grower may make, but giving a guaranteed sale.

Market Research

One of the major keys to success in any business is to 'know your market'. If you know that there is demand for what you are planning to grow, and if you can pinpoint where that demand is, your chance of success will increase greatly (not to mention the sleepless nights you will save). So one of the most important things you can do before growing any new crop is to thoroughly research the market.

Successful marketing depends upon knowing the people/groups you are marketing to – what they want, how they are likely to react to your product, what they will spend money on etc. When the market place is understood, you can then follow the steps below to achieve successful marketing:

- Set realistic marketing goals
- Provide structures for reaching those goals
- Assess the results of marketing efforts and modify your approaches accordingly

Market research involves all those activities which help management reach marketing decisions. It attempts to make the unknown known; and in most instances, largely succeeds.

Steps involved in market research

What information is required? If there is a problem, define it. For example, how can I increase sales by 10%? ….. *or* should I change the way I distribute my produce?

- Conduct the investigation. Examine past records which relate to the problem. Speak with people in the know, who might help with this problem. Try to find any relevant information which has been published (e.g. in trade magazines, bureau of statistics etc).
- If more information is required, you may decide to survey the customers (or potential customers). Note: this involves significantly more cost.
- If the problem is still beyond you, you may employ a professional market research firm to handle it.

Gathering information

There are various ways you can obtain information about the market. After considering the possible marketing avenues (e.g. direct sales to the public, selling through major markets, contract growing etc.), and the type of produce you might grow; you should next try to find out all you can about the market you are considering. Get to know the details of how that market operates, what your chances might be of breaking into that market and how strong it is. This information can be gathered in three main ways: asking questions, observing people and referring to literature.

1. Asking people (i.e. surveys)
   Formal or informal, surveys can tell you a lot about a market. Surveys are relatively inexpensive and adaptable to a wide variety of situations. Questions are asked through personal interviews, mail questionnaires, telephone interviews etc.

- Mail and telephone surveys are less expensive
- Telephone surveys produce quickest results
- Personal interviews are the most accurate

2. Watching people
   Much can be learnt by observing people in the market place. Visit a fruit or flower shop and watch what they buy, what produce they are attracted to, and how they buy. This involves observing reactions when something is presented to people. Some growers get excellent feedback from the public when they put on a promotional display at an agricultural or trade show. The main disadvantage is that observations may not be accurate.

3. Literature
   Magazines, newspapers and books are a great source of information. They can give a very good indication of what markets are most viable; however, literature is not always up to date. Material published today may have been written

months or years ago, and may not be an accurate reflection of the situation. Newspapers and monthly magazines are generally better than quarterly journals or books.

What Do You Need To Research?

In any business, success is determined by a combination of many factors, and different factors are relevant in different situations. However, the following areas are commonly researched:

- Progressive or backward (Is the market for your proposed produce expanding or contracting?)
- Is the competition helpful and courteous to customers…or not?
- Does the competition give quick and efficient service?
- Is the produce you have in mind advertised/promoted well or poorly in the marketplace?
- Is the produce you are considering inexpensive or expensive?

How to Sell Successfully

Whether you sell direct to the public or only deal with contractors or agents, you will find some basic sales skills can be invaluable. Often your ability to sell is the difference between a successful hydroponic business and financial disaster. When you negotiate a sale, be prepared and make sure you know the following:

- Details of what you are selling; its attributes, its competition, its negative points (and how to counteract these).
- Where and how to find the product/brochures/catalogues/order forms…or anything else relating to the sale.
- The prices to charge and terms of sale.
- Procedure for making a sale (including using cash register, filling out order book, writing receipt etc).
- Company policies (on returns, damaged goods etc).
- How to package and deliver goods or services (e.g. wrapping, directing other staff to deliver service or goods etc).
- How to keep records in order.
- How to maintain order and tidiness in sales area/equipment etc.

Key Rules Every Salesperson Should Follow

- Research your customer and product first. (You need to know both the customer and the product before you attempt to sell).
- Find out everything your customer needs to buy before you start dealing.
- Highlight the benefits of a product rather that the features. (Tell the customer what it can do for him personally…don't tell him what is great and unique about the product if it is not relevant to him in particular.)
- If there are objections, play it cool and try to determine very specifically what they are – once you narrow down the objection, put it into perspective by showing something about the product which compensates for that objection (e.g. yes it is expensive – but it will sell better).
- Always keep control of the conversation – don't let yourself get into a defensive position. This is done by asking questions when the customer starts to take the offensive.
- Do not talk while showing the product. Show them and then stop and talk, stop talking while you show them again…etc.
- Handle produce with respect.
- Get the customer to try out the product (e.g. give him a strawberry to eat or a flower to smell).
- If you need to, use the phone or calculator to buy thinking time (excuse yourself to make a phone call or calculate some figures).
- Try to close the sale – ask for an order at the appropriate time, when the customer seems to be in a state of mind where he/she is likely to buy. (Many a good sale is lost because the salesman doesn't close the deal when he has the chance. Once you and the customer part ways, the chances of getting back together to finalise the deal are greatly reduced).
- Remember that fulfilling the customer's needs is more important than improving your own knowledge or sales technique.
- Do not forget that the customer is always right; without him you are not going to remain in business.

strawberry packaged

CHAPTER 17 : TROUBLESHOOTING: A GUIDE TO OVERCOMING PROBLEMS IN HYDROPONICS By Lynette Morgan

NUTRIENT LEVELS

Hydroponic systems are reliant on the composition and formulation of the nutrient solution to supply all the essential elements required for optimal plant growth and yields. However, nutrient solutions are complex and the composition of these changes as they flow through the root system and irons are extracted. Many problems in hydroponic systems are either nutrient or environmentally based, making these the main areas where troubleshooting skills need to be developed.

The most common nutrient problem is the development of deficiencies of one or more elements, either due to rapid uptake or unsuitable nutrient formulations and management, which are common mistakes made by many hydroponic growers.

Deficiencies in hydroponic production are more common than toxicities as plant uptake of many elements has the potential to strip out nutrients at a rapid rate, particularly from recirculating solutions. The most common deficiency problems in hydroponic crops are potassium in fruiting plants such as tomatoes, iron under certain environmental conditions, nitrogen in some highly vegetative crops, and calcium in many species such as lettuce, tomatoes and capsicum.

To complicate hydroponic plant nutrition further, deficiencies as they occur in different crops may or may not be a result of an actual deficiency in the nutrient solution. Potassium can certainly be stripped from a nutrient solution rapidly as fruit develop and expand, and also because luxury uptake occurs in many crops. However iron, calcium and magnesium deficiencies on leaves and fruit occur even when there is more than sufficient of these elements in solution. These induced deficiencies often fool growers into thinking there is a problem with the formulation of their nutrient, when the cause is often more complex.

Iron

Iron deficiency is common under cool growing conditions, where the root system might have become saturated, damaged or where the pH is running high.

Magnesium

Magnesium deficiency on crops such as tomatoes can be induced by high levels of potassium uptake.

Calcium

Calcium deficiency which shows as tip burn on lettuce and blossom end rot of tomatoes and peppers is a calcium transport problem within the plant, rather than a lack of calcium in the solution. It is induced by environmental conditions such as high humidity which restricts transpiration and calcium distribution.

Solutions

Working out if deficiency symptoms on a crop are actual or induced by other factors becomes the vital first step to solving such problems. The simplest way for a grower to determine this is to have a full solution or leachate analysis carried out to rule out any deficiency in the plant's feed regime. Low levels of an element in solution (below the optimum being aimed for) certainly indicate that the nutrient is the problem and boosting levels of the deficient element will rapidly help correct the situation. Some deficiencies, particularly of the trace elements such as iron, benefit from foliar application of these nutrients to help correct the problem in the short term. These however are only a quick fix and the missing nutrient needs to be supplied in the root zone at the correct levels over the long term. Iron foliar sprays are particularly effective where cool conditions or root zone damage have limited iron uptake and caused the distinctive iron chlorosis symptoms on the new leaves.

measuring nutrient levels

SALT BUILDUP AND EC PROBLEMS

Salt or nutrient buildup/crusting is often seen in hydroponic systems, particularly in crops grown over a long season or with media used for several years. Salt buildup appears as white/off-white crystalline crusts or residues on the surface of growing media and sometimes even on the base of plant stems where it can cause salt burn damage.

Certain types of media are more prone to this nutrient problem than others – those with porous structures and high rates of water loss from the substrate are more prone to salt crusting than others. Expanded clay granules and similar media often develop a whitish coating on the surface after a few months use, and this can be common in ebb and flow systems. Media beds which are covered with plastic film – as in the case of rockwool slabs – rarely develop these salt deposits on the surface as the film prevents excessive moisture loss from the media which results in salt buildup.

Salt buildup occurs when a medium which has been thoroughly wetted with nutrient solution containing dissolved salts, loses moisture to evaporation faster than the minerals are taken up by the plant's root system. In this case the moisture is lost to the atmosphere but the minerals stay behind, thus increasing the EC in the media and around the roots. This salt buildup in the root zone can cause damage both through direct contact with the salt crystals around the delicate plant stem, particularly in seedlings, and by increasing the osmotic pressure around the plant roots.

Fortunately salt buildup is easily dealt with once growers recognise the symptoms – white crusting is the first sign, as is plant growth which becomes stunted, dark, hard and unusually slow. As salt accumulation becomes more severe, the stem area at the base of the plant and roots can be burnt and die back, resulting in wilting during the warmer times of day and, as the problem progresses, disease attack in these areas.

Regular monitoring of the EC of the nutrient solution draining from the media helps prevent and diagnose salt accumulation problems – ideally the EC of the feed solution should not increase as it flows through the root system. If the EC is increasing as its flows through the root system and out the base of the growing container, then salt build is likely to occur. However, even plants fed a low EC solution can develop salt accumulation where the atmosphere is dry and high rates of water loss from a porous medium occur. In this case, the medium will benefit from some leaching from time to time and a thorough clean between crops (or even replacement in severe cases). Some growers prefer to leach excess salts from the growing medium using plain water; however when an actively growing crop is present this can have negative effects as the sudden drop in osmotic pressure in the root zone triggers a large influx of moisture into the root cells which can in turn result in fruit splitting and soft, weak vegetative growth. Flushing growing media with either a specifically designed 'flushing solution' or a 1/3 strength nutrient is recommended to remove excess salts from the root zone. Carrying this process out every few weeks may be required in certain hydroponic systems, such as shallow flood and drain or tray systems in warm climates with high evapotranspiration rates, and often between crops if media is to be reused.

SODIUM TOXICITY AND ACCUMULATION

One of the most problematic elements in hydroponic nutrient solutions is sodium. Many large hydroponic installations must rely on ground water sources, many of which naturally contain sodium and other undesirable elements. Oceanic countries and regions often have high sodium levels in bore and rain water and this can become a major problem in recirculating systems and even in drain-to-waste media systems as it tends to accumulate rapidly under conditions of high evaporation and transpiration. Plants don't require large levels of sodium, thus the levels of this element build up in the solution or media until it is dumped and replaced. Dumping of the solution is a costly, time-consuming process which is not seen as environmentally friendly, particularly where the solution contains sodium accumulation. However, some crops and systems are more tolerant of sodium levels in the water supply and avoiding growing sodium-sensitive crops is often advised where high levels of this element are continually present.

Accumulation of undesirable elements such as sodium in recirculating nutrient solutions are dependant on the original composition of the water source, since more and more of this element will be added each time the water is topped up. While it may take some time until an element such as sodium builds up to toxic levels, it does cause the problem of adding to the EC level of the solution. For example, if an EC of 2.0 is being maintained, 0.4 - 0.5 units of this could be due to sodium, thus reducing the levels of macro and micro elements available to the plant, while still providing the same osmotic pressure. For this reason, it is essential that growers know the sodium content of their water supply and the rate at which this accumulates in recirculating solutions.

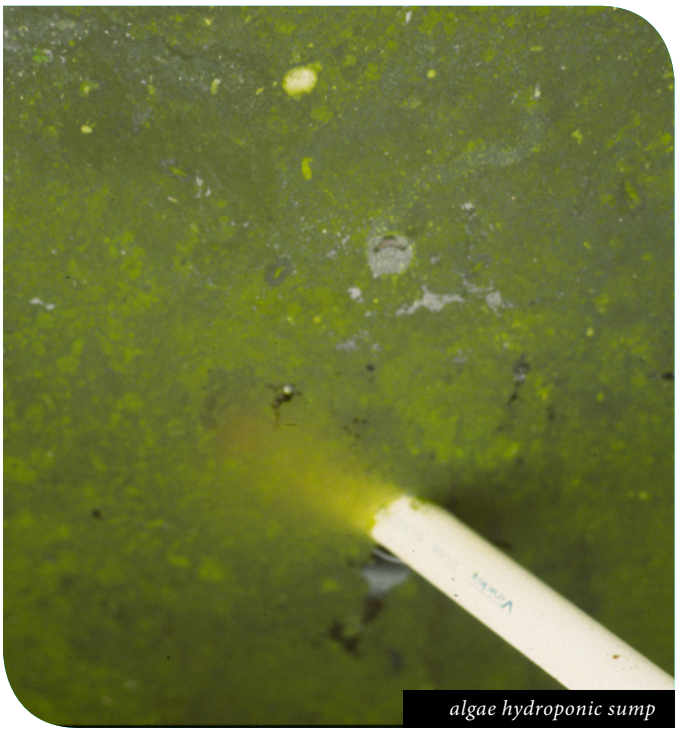
Much research has been carried out on the effects of sodium in solution on fruiting crops such as tomatoes, which are fairly salt tolerant, but little information is available on more sensitive crops such as lettuce. Recommendations as to the maximum allowable levels of sodium in solution, and at what point crop yield and quality losses occur due to the build up of this element are not clear and often vary considerably. In recirculating systems, levels as low as 50 ppm of sodium can have a negative effect on growth of crops such as lettuce, herbs, salad greens, strawberries, roses and a few other cut flower crops. More salt tolerant crops such as tomatoes can withstand sodium levels in excess of 250 ppm, before any negative effect occurs. If sodium, being a non-essential element, is continually introduced via the water supply, it will continue to build up unless the solution is bled or dumped from the system.

Sodium is toxic for certain processes in the plant. In the foliage, it reduces photosynthesis and enzyme reactions, however, plants do have the ability to block sodium absorption into the leaf. Research in the Netherlands has shown that in capsicum plants, grown in a solution containing relatively high levels of sodium, a large proportion of the sodium in the above- ground part of the plant is very efficiently withdrawn from the transpiration stream into the stem pith. This protects the leaf processes and also leads to low sodium levels in the fruit. However the sodium which becomes stored in the stem pith seems to leach back out of the plant if the feed solution is replaced by a low sodium solution. This leads to a salt increase in the feed solution, indicating that it is best to replace only a portion of the nutrient solution several times, than to completely dump and replace with fresh solution. It is known

that plants can adapt to gradually increasing salinity of a nutrient solution, however some species have a greater ability to do this than others. It has also been found that the addition of soluble silica to nutrient solutions provides some protection against potentially toxic levels of sodium. The best option for growers using water which contains sodium is to monitor the build up of this element in recirculating nutrient solutions or nutrient leachate from media systems and use this information to decide how often the solution must be totally or partially replaced to prevent accumulation of plant damaging levels. In some cases, reverse osmosis needs to be used to remove excess ions from a water supply before it is useable for hydroponic nutrient solutions and top up water.

WHEN NUTRIENTS GO BAD

The nutrient solution in hydroponic systems provides an ideal environment for a number of other forms of life to grow and multiply. Plant life such as algae is common, and microbial populations exist in most healthy nutrient solutions unless some form of sterilisation is used. Nematodes, insects such as mosquito larvae and others, can proliferate in some nutrients and may cause plant growth problems. Nutrient solutions provide the ideal breeding ground for many plant pathogenic fungi and bacteria since they contain mineral elements, usually some organic matter, moisture and are often warmed to just the right temperature for optimum microbial growth. Bacteria, fungi and algae are also very commonly carried in water supplies, on media, seedlings and old root systems, on equipment, transported by humans, animals, wind and in dust, making complete avoidance difficult. Despite this, most well run hydroponic systems don't often have problems with odour, bacterial growth or insects, but when they do establish, control needs to be swift as certain nutrient problems will rapidly cause root death and plant decline.



algae hydroponic sump

ALGAE

Most hydroponic growers come across algae sooner or later. It appears as a green, brown, reddish or black, slimy growth which clings to channels, gullies and pumps or spreads over the surface of damp media. Long strings of algae are common in nutrient tanks and return channels and the speed at which this form of plant life can grow and multiply is often impressive. Algae usually has an earthy or mouldy smell, and large volumes of decomposing algae in the nutrient can be responsible for unpleasant odours.

Algae is a nuisance to any grower as it not only looks unsightly, but has the ability to block drippers, emitter, pumps, return channels, filters and heavy growth can even seal off the surface of growing substrates, robbing the roots of oxygen.

The problem with algae, apart from the appearance and smell problems it can create, is not so much that it competes for nutrients with plant roots, but as it blooms, dies and decomposes, it sucks up dissolved oxygen from the system. This increases the biological oxygen demand (BOD) on the system and causes root suffocation from a lack of oxygen. Decomposing algae may also release toxins as it breaks down and provides a food source for plant pathogenic fungi which may then multiply to high levels in the system. Algae directly attached to plant root systems can suffocate the roots, making the plants prone to attack by opportunist pathogens such as *Pythium*.

Algae, is a form of plant life, and it is a natural consequence of exposing water with nutrients dissolved in it to a light source. Where there is no light, algae cannot grow, so the best solution to preventing algae growth is to stop light from reaching the nutrient solution where ever possible. Channels should have light-proof covers; return gullies also benefit from covers; large media beds can also be covered with either plastic film or a layer of substrate which is designed to act as a 'dry mulch' since algae can not grow on dry surfaces.

In aeroponic systems, the root chamber must be light proof and media pot or container systems can use plastic or rigid collars which cover the surface of the media. Plastic collars are available these days for rockwool propagation cubes – a surface which is usually green with algae by the time seedlings are ready for planting. However, even in the best designed system, there is usually somewhere that light will fall on the nutrient – planting holes in NFT, return outlets in channels and tanks are common areas.

Control of algae, once established in a hydroponic system can be difficult – most growers tolerate small amounts of algae in the systems provided it does not become excessive. A regular scrub out between crops will often remove stubborn algae and is often the only control used by commercial growers.

Some growers do add algaecide products into the nutrient to kill off algae and there are a number of these products on the market. However, since any product which kills algae, a form of plant life, can also damage young or sensitive root systems, care must be taken with the dose as damage has been known to occur. Algae will also regrow very quickly after applications of most algaecide products, requiring regular applications to maintain good control.

Hydrogen peroxide can also be added to the nutrient solution to kill of existing algae. However it has been found that dose levels of 50ppm of hydrogen peroxide (H^2O^2) is required to control algae, a rate which was phytotoxic for young plants, although older

plants survived this dose rate. Therefore careful and selective use of H2O2 could be used on older, more resistant plants, but since H^2O^2 is a biocide rather than just an algaecide, there is always a risk of root damage.

ROOT DEATH

The major causes of root death in hydroponics are suffocation, starvation, pathogens, chemical damage, temperatures and EC/pH problems. In hydroponics, suffocation is probably the leading cause of root death and reduced growth rates. Often, any pathogens present won't attack a healthy root system until it is damaged or weakened by adverse conditions – usually stagnation or suffocation in the root zone.

A lack of oxygen can be caused by flooding or ponding of the nutrient solution, decomposing organic matter in the solution, slow flow rates, and too many plants robbing oxygen from the root zone, which is accelerated as conditions become warmer. A lack of oxygen reduces the permeability of roots to water and toxins will accumulate as the root cells die. Some plants such as tomatoes, will attempt to adapt to the lack of oxygen by producing adventitious roots on the lower stem and swelling at the stem base.

STARVATION

A lack of nutrients will affect the root system just as it does the top of the plant. However, the symptoms are more difficult to observe. A phosphate deficiency will cause the roots to become brown with a reduced number of lateral branches. A lack of calcium will induce a thin, poorly developed, brown root system. Manganese deficiency will cause a small root system that is much shorter and finer than usual with some browning of the root tips. Copper deficiency results in severe underdevelopment of the root zone. Boron deficiency causes the root tips to become jelly-like in appearance.

SANITATION

Many products and chemicals that are used to sanitise hydroponic systems and equipment between crops are effective at killing pathogens. However, residues of these chemicals that aren't completely washed away before the seedlings are planted can cause a number of problems, including root death. For example, chlorine is a common sanitation agent, but it can burn off young roots – even at low concentrations – so care must be taken to rinse off all traces of chlorine before replanting the systems. Hydrogen peroxide at levels as low as 7ppm has been shown to damage the root system of young lettuce plants and should be used with care.

EC AND PH

An electrical conductivity (EC) level that is too high for the crop being grown will result in severe stunting of the root system. If the EC reaches extreme levels, water will be lost from the root cells back into the nutrient solution to the point where root death will occur. This is more common in crops that prefer a lower EC level such as lettuce.

Likewise, pH levels that are too high or low can induce root damage and nutrient uptake problems. However the pH range that plants can tolerate without any negative effects is fairly large. It has been found that the appearance of the root system differs in hydroponic plants that have been grown at different pH levels. Plants grown at a pH of 7.5 and above have a shorter, coarser root system than those grown at a pH of 5.5. Higher pH levels reduce the availability of certain elements in solution, mostly iron and manganese, and may induce deficiency symptoms.

NUTRIENT TEMPERATURE

Often, a brief period of cold or heat will stress and damage the root system. However root regeneration is usually rapid when conditions improve again. For example, if hydroponic strawberry plants are chilled, most of the root system will become blackened and may die. But when conditions warm up again as the plant is put into a heated greenhouse, healthy white roots emerge from the base of the crown. Also, a nutrient solution that is too cold or too warm will result in a root system that doesn't fully extend. The roots will remain stunted since the root tips don't want to grow into the solution. High or low temperatures in the root zone also stress the plant and reduce the rate of nutrient and water uptake. This stress also weakens the plants, making attack by root pathogens more likely.

ec meter

ROOT PATHOGENS

Root diseases are a major concern for hydroponic growers. This is particularly true of growers who use NFT and other recirculating systems that could quickly transport pathogens to a large number of plants. Some pathogens that can attack roots in hydroponic systems have symptoms that make them easy to identify with some practice. However, others may not have any symptoms at all. One aspect these pathogens all have in common is their ability to reduce plant growth and yield. Detection kits are available for many root-attacking pathogens. Also, sample tissue can be sent for correct identification to a number of facilities. But for most growers, examining the root zone is the first line of defence against root pathogens.

The most common pathogens that effect roots in hydroponic production are *Pythium, Phytophthora, Fusarium, Olpidium, Plasmopara, Didymella and Verticillium*. Others have also been reported to cause crop losses – in fact about 20 fungal, four viral and two bacterial pathogens exist that are commonly associated with root diseases in hydroponic vegetable crops.

Root pathogens can infect hydroponic crops from a number of sources, including air, water, media, insects, infected plant material, seeds and dust. Airborne root pathogens are rare, but have been known to occur. A more common source of infection is soil, which hosts a huge number of inoculum. Soil can enter a hydroponics system on the shoes of staff, as dust in the air, in media, on equipment, or in water, particularly from exposed sources such as reservoirs, rivers and streams. Also insects such as shore flies and fungus gnats can carry pathogens.

Since many root problems and odd symptoms are caused by pathogens, and such attack is often induced by stressed plants, cultivating a healthy crop is always a growers first line of defence. Ensuring adequate oxygen is present in the root zone throughout the hydroponic system is essential. Sometimes environmental or cultural problems exist that stress the plants without the grower's knowledge. Therefore observing the root zone on a regular basis is vitally important. In media-based systems, a grower who notices a plant showing signs of wilt or discoloration should pull it out and examine the root system. Once any plant has been identified as potentially having a root disease, it should be removed from the cropping area and destroyed. Proper sanitation and hygiene in hydroponic systems is also important for pathogen control. Root pathogens can carry over from one crop to the next and any media or substrate that contained infected plants should be discarded. In areas where there are high populations of root disease pathogens, commercial growers need to consider some form of control such as treating the water supply with UV light, hydrogen peroxide or ozone.

FRUITING PROBLEMS IN HYDROPONICS

Fruiting crop problems in hydroponics can range from a simple lack of fruit development to more complex physiological disorders such as blossom end rot (BER). Many growers have experienced fruit with skin disorders such as uneven coloration, blotch, crazing, streaking, silvering and other unidentified spots. Fruit splitting can be common in crops such as tomatoes. Capsicums and cucumber can become grossly misshapen. These disorders are largely physiological, environmental and cultural.

Flower and Fruitlet Drop

Most common hydroponic crops will flower when they have reached their appropriate point in development. One frequent problem is flower drop. There are many potential causes of flower and fruitlet drop in hydroponic crops – some are internal and caused by plant stress and some are environmental. In many crops, flower drop in induced by high air temperatures. However the point at which this thermal stress occurs varies for each crop and cultivar. Low light levels that limit the growth of the whole plant can also induce drop, particularly where low light is combined with high temperatures. Although not as common in hydroponic crops as those grown in soil, mineral deficiencies, such as low levels of nitrogen and/or phosphorus (P) in the nutrient solution, can retard flower and fruit development and cause drop. Flower drop can also be caused by water stress – either a lack of irrigation or high EC levels.

With the development of high-yielding greenhouse cultivars, another major cause of flower and fruitlet drop has become heavy fruit load or excessive vegetative growth. Young, newly developed leaves compete for assimilates with the flowers and fruitlets already on the plant. If assimilates are transported to these new leaves at the expense of the flowers, drop can occur. This is more common in situations where assimilate production is limited due to low light or other reasons. Lowering plant density, use of carbon dioxide and cultivars less prone to drop assists growers to prevent these types of problems which often occur in winter. The presence of a heavy fruit load developing on the plant has the same effect – new flowers and fruitlets may be sacrificed in favour of the rapidly developing, larger fruit already present. In certain crops a lack of pollination may be the cause of flower and more commonly, fruitlet drop.

APPENDIX

COURSES AND EDUCATION IN HYDROPONICS

ACS Distance Education

ACS Distance Education offers a range of vocational and higher learning courses in horticulture, agriculture and hydroponics. A full range of courses offered can be seen on the internet.

ACS Distance Education
P.O. Box 236
Wallingford, 0X10 OWJ,
United Kingdom
Phone: 0800 328 4723 (within UK only)
www.acsedu.co.uk
admin@acsedu.co.uk

Short Courses

- Home Hydroponics is a short course for the beginner hobbyist
- Hydroponics I provides a foundation course for the serious grower, providing a broad based grounding in all aspects of hydroponic culture. This course is available by traditional distance education, or by online study - see www.acseduonline.com
- Hydroponics II (Hydroponic Crop Management) is a new course dealing principally with the management of the most important commercial crops.
- Certificate in Hydroponics is a 600 hour course designed to train people to work in the hydroponic industry.

These and other courses are available from the following colleges:

The Australian Correspondence Schools (ACS)

ACS offers over 150 additional horticulture courses including certificates and diplomas with options for further study in hydroponics. Videos on various horticultural subjects have also been produced and are available through ACS.

The Australian Correspondence Schools
P.O. Box 2092, Nerang MDC,
Qld, Australia, 4211
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www.bluelabassist.com/index.html

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P.O. Box 6067,
Concord,
California, U.S.A.
hsa.hydroponics.org

Hydroponic Society of S.A.
c/- Bruce Retallick
12 Jikara Drive,
Glen Osmond, Australia, 5064

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136 Heathmont Road,
Heathmont,
Victoria, Australia 3135
(03) 9729 5170

Hydroponic Society of Western Australia
c/- M Biggs
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Mandogalup, Australia, 6167

International Society for Horticultural Science
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www.ishs.org/

International Society of Soilless Culture
Headquarters: P.O. Box 52, 6700 AB Wageningen,
The Netherlands.
Australian contact: Keith Maxwell
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